HYDRO - ELECTRIC DEVELOPMENT
ON THE
DESPLAINES RIVER

BY
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ARMOUR INSTITUTE OF TECHNOLOGY

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Design of a proposed
hydro-electric development

DESIGN OF A PROPOSED HYDRO-ELECTRIC DEVELOPMENT
ON THE DESPLAINES RIVER AT
DRESDEN HEIGHTS, ILL.

A THESIS
PRESENTED TO THE
PRESIDENT AND FACULTY
of
ARMOUR INSTITUTE OF TECHNOLOGY

by
Marston Curtis
W. G. Stansel

FOR THE DEGREE OF
BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

and by
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LOCATION.

The proposed hydro-electric development exemplified in this thesis takes into consideration a site on the Desplaines River at Dresden Heights, Illinois, very nearly on the line between Will and Grundy Counties. The site is about one thousand feet above the mouth of the Kankakee River, at which point it unites with the Desplaines River to form the Illinois River. On the north bank, running parallel with the Desplaines and the Illinois Rivers, is the Illinois and Michigan canal. The height of the water in the canal is about 16' above the Desplaines River and the two streams are separated by an earthern gravity dam.

RECONNOISSANCE.

The original intention was to design as a thesis a hydro-electric development at Big Dresden Island, on the Illinois River, which is about one-half mile below the above site. Upon our visit to the vicinity of the island the project was abandoned, owing to the fact that the island is very low, as was also the south bank of the Illinois River. It was seen that in order to utilize the flow of the Kankakee River and the Desplaines River at this point a very long dam would have to be built, and it was found

on further investigation that the bed rock was not as accessible as at the site chosen, being overlaid with four or five feet of gravel. Moreover much of the low land of the Kankakee valley would be flooded. It was not thought practical to develop the variable flow of the Kankakee River for the above reasons.

PHYSICAL CHARACTERISTICS.

There is a peak in the underlying Niagara limestone at this point of the Desplaines Valley and the bed rock lies at or very near the surface on both sides of the river. The river bottom is stripped of silt as shown by the series of rapids immediately above the dam site. The rock is hard and compact and forms an easily accessible and excellent foundation for the dam and power house.

The south bank is low lying and is frequently flooded. There is a deposit of from three to five feet of loam over the bed rock which must be excavated for the foundation of the dam. The river channel on this side is not well defined. About 1,500 feet above the site there is a slough called the Kankakee Cut-off, over which the Desplaines River discharges into the Kankakee River during high stages. It will be necessary to construct an earthen

dam or levee across this slough to prevent the discharge into the Kankakee River. The north bank of the river at this point is the south bank of the Illinois and Michigan Canal and is high and strong enough to withstand the flood flow in the Desplaines River.

ILLUSTRATIONS.

I. This view shows the convergenceof the Kankakee River and the Desplaines River to form the Illinois River. The Kankakee River flows in from the left background, the Desplaines from the left forming the larger body of water which is the Illinois River. In the foreground is the Illinois and Mighigan Canal. The construction machinery and ruined cofferdam was left by the contractor for the construction of a plant by the Economy Light and Power Company. The large volume of water flowing from the Desplaines River is shown by the standing waves in the middle ground. This picture was taken at medium stage.

II. This view shows the Illinois River about a half mile below the dam site. Big Dresden Island is in the left background. This site for the location of a power development was abandoned, due to the low banks and to the complications that would be caused by the extreme variation in flow from the Kankakee River.

III. This view shows the existing rapids at the proposed dam site. Bed rock underlies the site.

IV. This view shows the limit of back water on the Du Page River. The head at this point will be nearly distroyed by the backwater from the proposed dam. However, the dam shown in the view was not constructed for power purposes, but to maintain the level of the Illinois and Michigan Canal.

I

II

III

IV

STREAM FLOW OF THE DESPLAINES RIVER.

Maximum. In 1883 the river rose to an elevation at the dam site of 514.6' Memphis datum and to 516.5' at Jackson Creek, five miles above. This flood was due to the formation of ice gorges. Authority - "Profile of the Desplaines and Illinois Rivers", made under the direction of a Board of United States Engineers. A gauge was subsequently located at Jackson Creek by the United States Geological Survey and an exterpolation from their rating curve gives a discharge of 26,800 sec. ft., natural flow. The drainage area above Jackson Creek is 11,070 sq. miles, or 222 sq. miles less than the drainage area above the dam site. Considering a maximum runoff of 14.28 sec. ft. per square mile (see Meades' "Water Power Engineering" p. 745) there will be an additional stream flow of 3,170 sec. ft., making a total of 29,970 sec. ft. of natural flow from the Desplaines Valley at the dam site.

The flood of 1904 uncomplicated by ice gorges rose to a height of 513 ft. at Jackson Creek. In a manner shown above, this corresponds to a total stream flow at the dam site of 22,970 sec. ft., 4,940 of which is artificial flow from Lake Michigan.

Minimum. The "Profile of the Illinois and Desplaines Rivers" shows that in 1883 the river fell to an elevation of 500.3' Memphis. The rating curve exterpolated indicates a discharge of 1600 sec. ft. Considering the minimum runoff of the remainder of the valley to be negligible, gives the natural discharge of the dam site of 1600 sec. ft.

The minimum water recorded by the United States Geological Survey was 4200 sec. ft., including the artificial flow from Lake Michigan. But this artificial flow averaged 4940 sec. ft. in 1904. Evidently the natural flow was very small and it is a fact that in the upper reaches above the end of the drainage canal the river frequently goes dry during the Summer months.

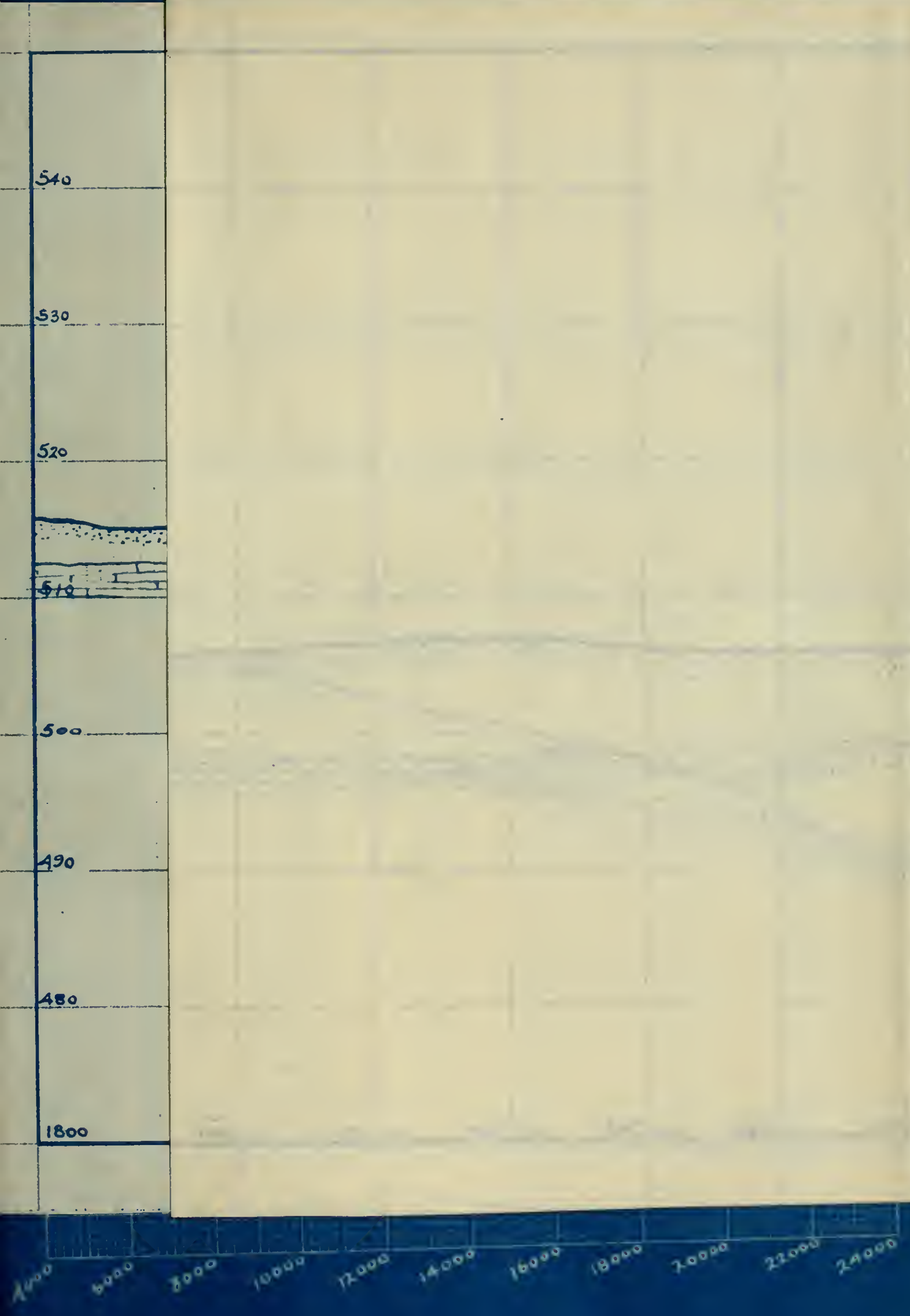
AVERAGE.

The proposed hydro-electrical development is largely dependent on the artificial flow from Lake Michigan through the drainage canal. The amount of flow is governed by the United State War Department, and the authorized amount at present is 4,167 sec. ft., but the Drainage Board has been using between 6,000 and 7,000 sec. ft. and at the present time is threatened with prosecution by the government for doing so. There has been an unfavorable report by Secretary of War Stimson sanctioning the proposed increase to 10,000 sec.ft.

But this report is not final as it may be referred to Congress as "a question of capital and national importance," as has been done in similar cases before, notably, when Mr. Taft when Secretary of War referred his adverse report on a proposed increase of 4,000 sec. ft. to drain the Calumet River to Congress for settlement. Representative Madden, it is expected, will introduce a bill at the present session of Congress, authorizing the proposed increase.

With the recent creation of the Sanitary District of Indiana an additional supply not yet determined will flow into the Desplaines River by way of the Little Calumet River and the Sag Canal and will be available for power at the dam site.

The natural flow of the Desplaines River, except during flood stages, is relatively small, and will average during the year about 1100 sec. ft., or about 500 sec. ft. at available stages.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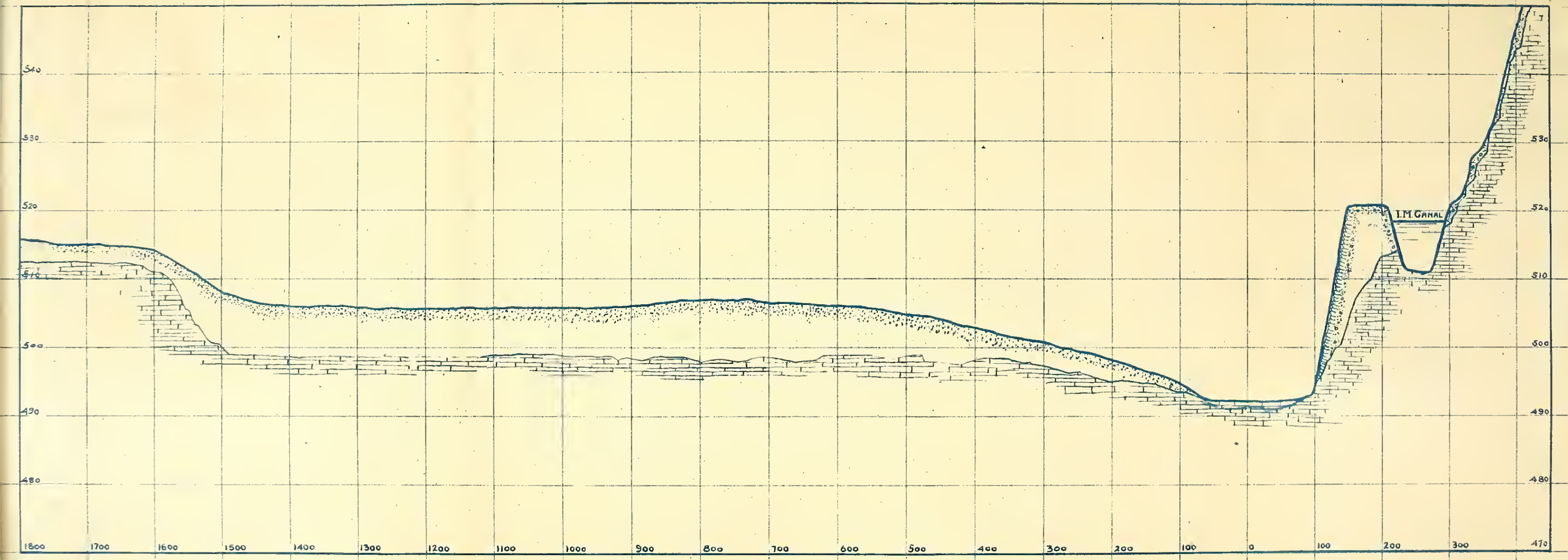
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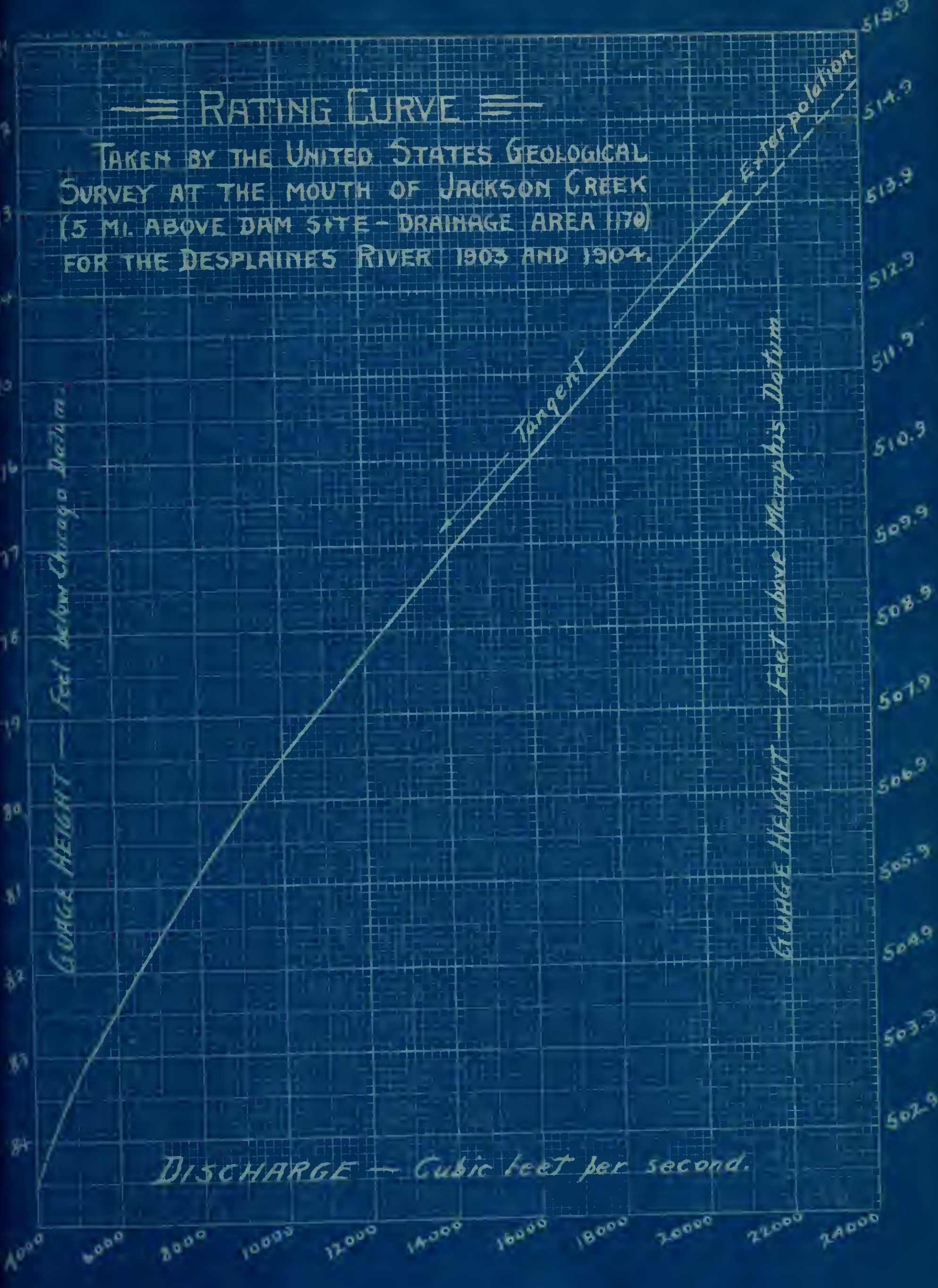
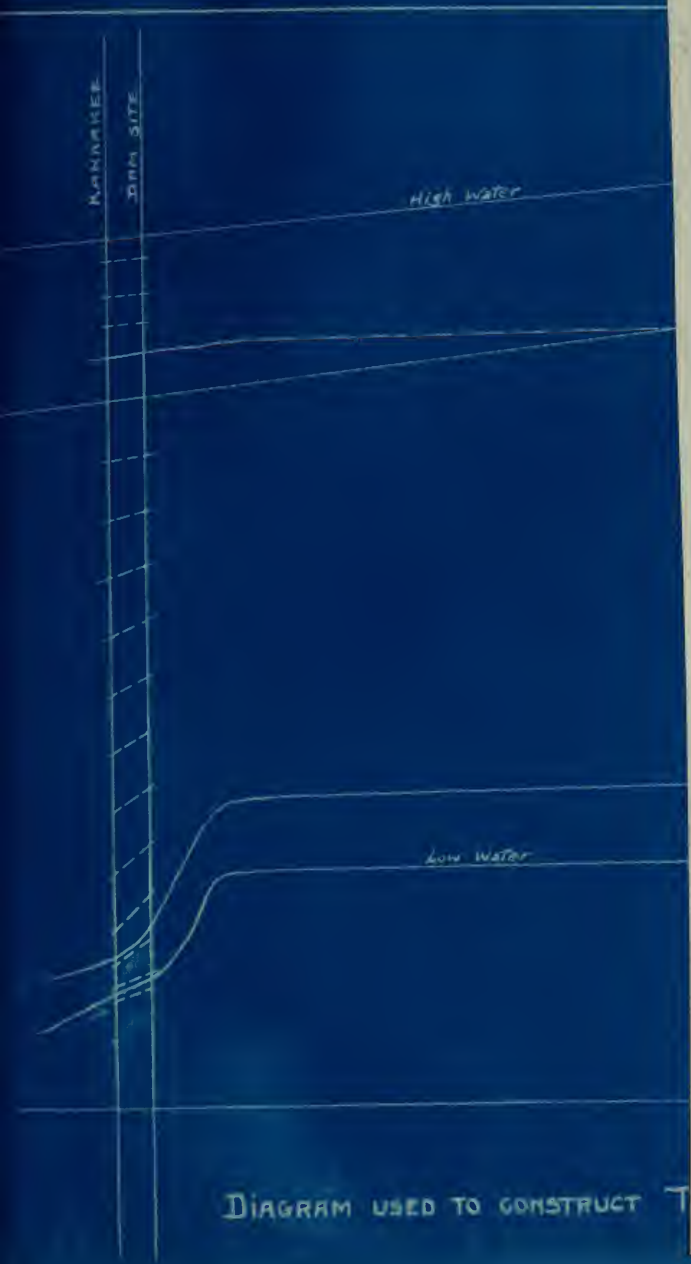


RATING CURVE

TAKEN BY THE UNITED STATES GEOLOGICAL SURVEY AT THE MOUTH OF JACKSON CREEK (5 MI. ABOVE DAM SITE - DRAINAGE AREA 1170) FOR THE DESPLAINES RIVER 1903 AND 1904.



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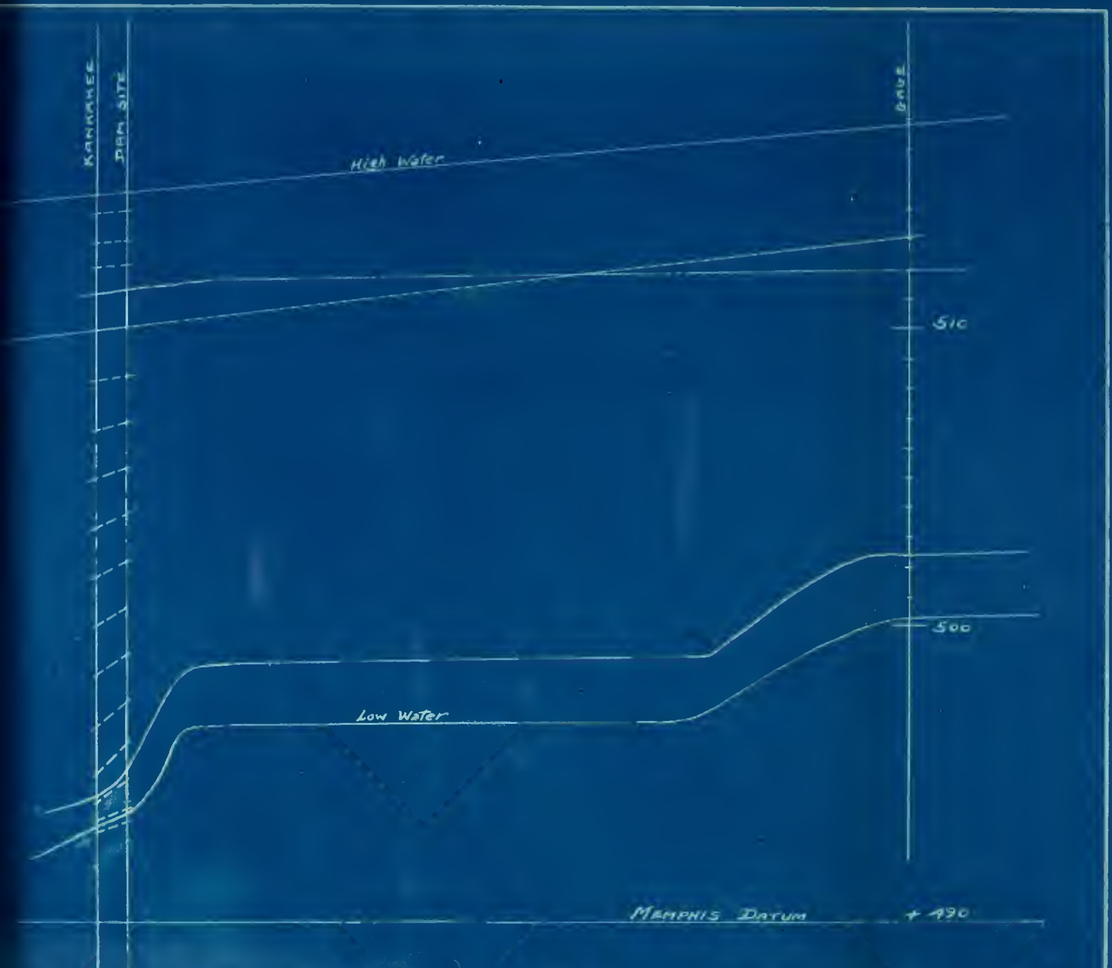
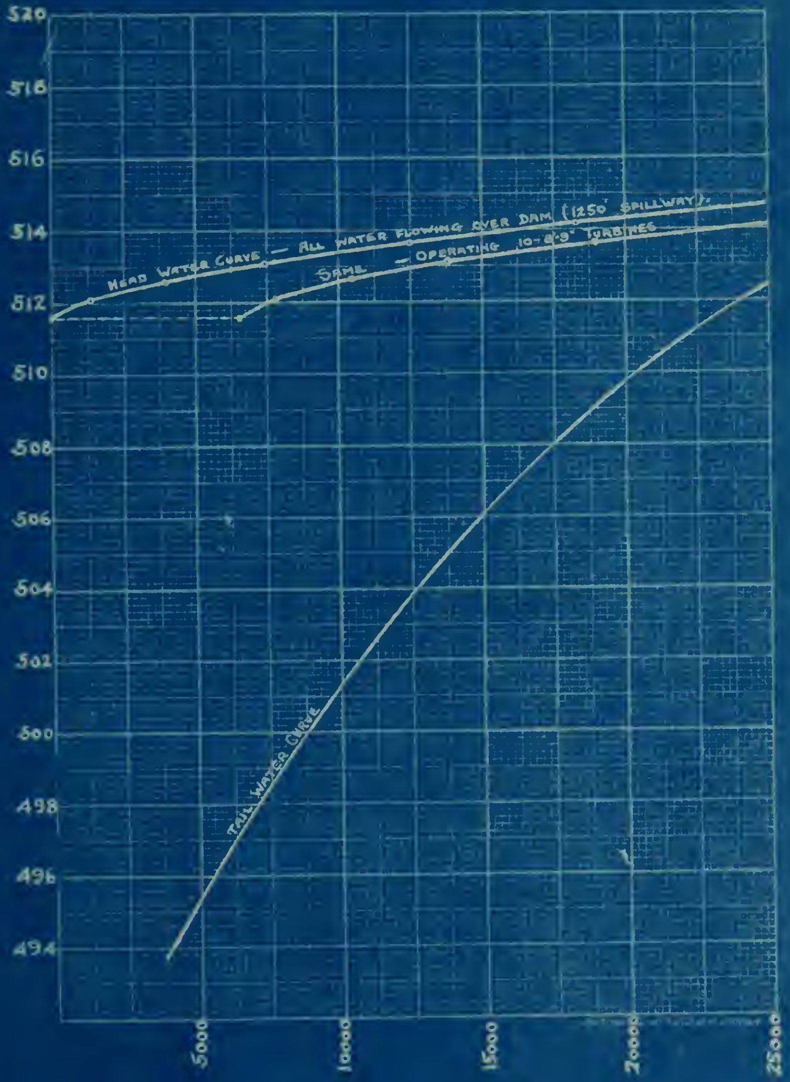


DIAGRAM USED TO CONSTRUCT TAIL WATER CURVE

SCALE 1" = 4000'
1" = 4'


HEAD WATER CURVE — ALL WATER FLOWING OVER DAM (1250' SPILLWAY).
SAME — OPERATING 10-8'-9" TURBINES
TAIL WATER CURVE
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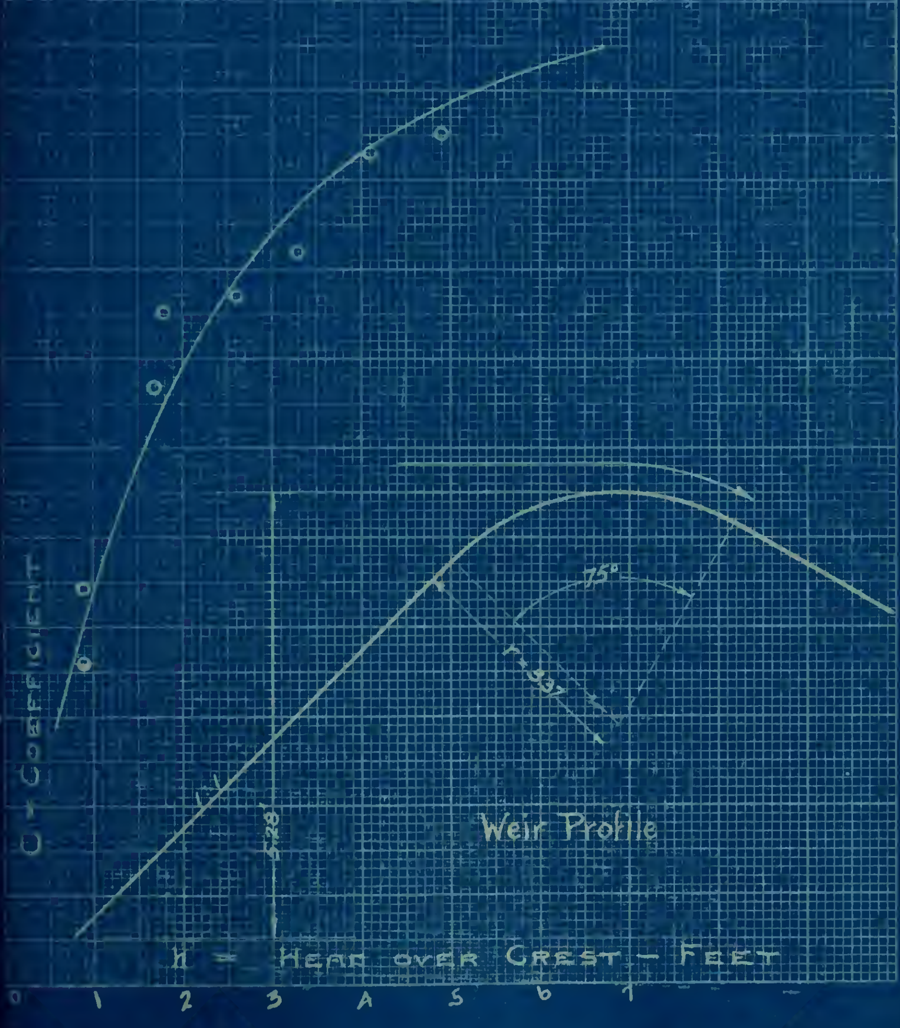
516
514
512
510
508
506
504
502
500
498
496
494
5000
10000
15000
20000
25000

Curve showing variations in coefficients with head in Bazin's formula for discharge over weirs ($Q = clh^{3/2}$). Points established fom experiments performed at Cornell University on weir with curved crest dimensioned below. Velocity head of approach included in h.



the parabola, to fit the conditions of this design is shown below.

Since the foundation is of solid limestone, no floor is necessary for this particular dam, and therefore the buttresses will rest on the bed rock.

This type of dam owes its simplicity to the fact that its upstream face is made so flat in slope (1 to 1 slope) that the water pressure has a vertical component which is equal to the horizontal component and this added to the weight of the deck and buttress is sufficient to hold the structure firmly on the river bed, against the forces tending to overturn it or slide it downstream. The fact that the upstream side is quite flat, tends to cause the resultant pressure to fall at or very near the center of the base. If properly reinforced and bonded together this type of dam is exceedingly strong and stable and must fail as a unit if at all.

To prevent water entering into the dam at the bottom, a cut-off wall, which extends into bed rock for three feet, is built along the heel of the dam. To provide for any possible seepage and to prevent upward pressure on the lower face drain openings which consist of 2 inch vent holes at 6 feet centers are provided. These openings connect the interior of the dam, with the tail water level.

Design of Deck

The dam which is 15.8 feet high throughout its length was designed for maximum conditions, namely, a maximum flood flow of 30,000 cubic feet per second, which gives 3.54 feet flowing over the crest. The first step was to assume the slope of the upstream side as 45 degrees to the horizontal. Then assuming a maximum thickness of 9 inches at the top of the deck, the required width at the bottom was determined by considering a one foot section, extending from buttress to buttress, and designing it as a continuous beam, carrying its own weight and the head of water acting on it.

Water Pressure-----------19.3 x 62.5 = 1200 lbs.sq.ft.
Weight------------------- 300 lbs. per sq. ft.
Total load--------------- 1500 lbs.
$M = 1/10\ wl^2$ = 1500x12x12x12/10 = 259000 in. lbs.
$M = f_s\,pbjd^2$
$f_s = 15000$ $p=.0075$ $j= .88$
d^2= 259000/15000x.0075x88x12=218
d = say 15"

where d is the distance from face of deck to center of the steel. Allowing 3 inches for covering, the thickness at the bottom of deck 15"+3" = 18 inches. The deck will be a trapezoid in section, being battered from 9" at top to 18" at bottom.

[illegible]

[illegible]

[illegible]

Test for Shear

The shear is maximum at the buttress.

Shear = 1500x6 = 9000 lbs.

Allowed stress in shear = 40 lbs.

bd40 = 9000

d = 9000/4x12 = 18.7"   O.K. for shear

Design of reinforcing at the bottom.

$M = f_s A\ jd$

$A = M/f_s\ jd$ = 259000/15000x.88x15 = 1.32 sq.in.

Use 3/4 inches square twisted bars at 5 inches spacing.

Actual A = 1.35 "

Test for Bond Stress.

allowable u = 150 lbs/in^2

$u = v/\Sigma\ jd$ in which V = shear j=.88 d=15"

Σo = summation perimeters.

u = 9000/6x.88x15   112 lbs/in2

∴ O.K. for Bond

The above calculations were repeated by taking sections along the deck in order to determine the steel required along the deck. From the table below it is seen that as the crest is approached less steel area is required.

Depth of Water	Load P	Shear S	Ben.Mom. M= $1/10Wl^2$	d^2 M/fspbj	Thickness reqd. d	AreaSteel Reqd. A	Actual steel used
19.3	1500	9000	359000	218	15	1.32	3/4" twisted at 5"
13.6	1040	6240	180000	115	12.1	1."	" " " "
11.4	860	5160	149000	125	11.0	1.03	" " " "
9.0	710	4260	122500	103	10.01	.92	3/4 twisted at 7"
Crest. 3.45							" " " "

The transverse reinforcing will consist of 3/8 inch round rods spaced at two foot centers. The deck will also be reinforced for negative bending moment. This reinforcing will consist of 3/4 inch twisted rods same as the bottom reinforcing, and will be spaced same but will extend only to the quarter points over the buttresses, making them 6 feet long. The transverse and longitudinal bars will be connected or held in place by means of steel wire.

Design of Crest

The crest is two feet six inches wide and eighteen inches thick. It will be designed as a continuous beam extending over buttresses, to carry its own weight and also the head on the crest during flood flow. The crest was made thick enough (18") to withstand ice action.

Water Pressure = 3.5x62.5 = 220#/sq.ft.

Own Weight = 2.6x1.5x 150 = 580# sq.ft.

Total weight acting per lineal foot of crest =800#

$M=1/10\ wl^2$

$M=800x12x12x12/10=138240$ in lbs.

$d^2 = M/\ fpbj\quad 138240/\ 15000x.0075x.88x12$ about 11"

$A=M/f_s\,jd = 138240/15000x.88x11=.95$ sq.in.

Use 3/4" of twisted bars at 7" centers.

Actual A = 0.96 "□

Face of Dam.

There is no definite way of figuring the reinforcing of the face. The face was made of approximately uniform section 9", and the reinforcing consists of 3/4" twisted bars at 12" centers. Transverse bars being 1/2" round bars at 24" centers.

Having designed the separate parts of the Dam, the next step was to obtain the length of the base, so that the resulting pressure of the separate

loads, the deck, crest, buttress, and face combined with the resultant pressure of the water, falls at or near the center. This was obtained by trial, taking different lengths of base, and repeating calculations. The data of the desired section is as follows:

Since the buttresses are spaced twelve feet apart and since the deck, crest and face all rest on the buttresses a twelve foot section was taken and the loads combined give a resultant passing through the buttress (taking into account weight of buttress). The weight of the deck was figured as a trapezoid in cross section, taking weight of a cubic foot of concrete as 150# . The crest was divided up into small trapezoids, whose areas were figured, multiplied by 150 and by 12 feet, the length of section. In the same manner the weight of the face was calculated. The water pressure for the 12 foot section was calculated by laying off to scalo the amount of pressure acting normally at the crest, due to head of 3.54 feet and then laying off the pressure at the base due to head of 19.3 feet. Since the pressure varies as the head, the resultant pressure acts through the centers of gravity of the trapezoids having these pressures as sides of the trapezoid.

The separate loads are as follows:

Weight of Deck – 45000# for 12' - 0" section
Weight of face – 212000# "
Weight of Crest – 6500# "
Water Pressure – 190000# "
Weight of Buttress-31600# "

The vertical loads were all combined by the method of moments, and their resultant was combined graphically with the resultant water pressure. The resultant load acting through the buttress for one section = 273000# and falls within three inches of the center of the effective base, which is 25 feet six inches. This small eccentricity was neglected and the pressure on the base is therefore considered as uniform.

Stability.

The strength of this type of Dam is largely dependent on the strength and stability of the buttress through which the total load is transmitted to the bed rock.

Test for Horiz. Shear on buttresses at base

Horiz. comp. of Water Pressure = 134330#
Allowed stress in shear = 40#
Effective base = 25.5 ft.
40xtx12x25.5 = 134330
t = 134330/40x12x25.5 = 11 inches

Test for Horiz. shear just above passage way through the Dam.

Horiz. comp. Water Pressure = 470x.707x116x12

t = 9.6"

As an added factor of safety the buttress was stepped into three sections, varying from 12" at top 15" at center and 18" for bottom section.

Due to the absence of bridges in the immediate vicinity of the plant, a passage way was designed, which will lead from the power house to the south bank. This passage will be 6'-6" and consists of a four inch reinforced floor slab carried by two 6" by 8" reinforced beams which are continuous over the buttresses.

Assume L. L. 100#/sq.ft.

" D. L. 40#/ sq.ft.

Weight per lineal ft. slab = 140x3.5 = 490#

Load on each beam = 245#

Assume weight /of beam = 70#

$M=1/10wl^2$= 320x12x12x12/10 = 56000 in. lbs.

d^2 = 56000/15000x.88x.0075x6= 95

d = 9.85 say 10"

h = 12"

$$A = M/f_s jd = 56000/15000 \times .88 \times 10 = .43$$

Use two 9/16" round rods

In slab use 3/8" round rods at 6" centers.

The deck, crest and apron of the Dam to be made of 1:2:4 concrete, the broken stone passing through a one inch ring. The remaining part, that is the cut-off walls and buttresses, to be made of 1:3:5 concrete, made up of crushed rock, sand and broken stone, passing a 21/2" ring.

DETERMINATION OF DAM PROFILE.

The Upward Curve. It is a well known fact that there is an upward curve to the lower side of a sheet of water discharging over a sharp-crested weir. If the crest of the dam is made to conform with this vertical curve of the water, the low water head may be added to without materially lessening the discharging capacity of the dam. The determination of the upward portion of the curve is practically impossible to determine theoretically, but on investigation, taking into consideration the slope of the deck of the dam, it was decided to continue the parabolic curve backwards and downwards from its origin about 18".

The Upper Portion of the Apron. This portion of the apron should also be built to conform as nearly as possible with the natural curve of the water, but at the same time be so constructed that the nappe of the water sheet will at all times adhere to the apron and not tend to create a vacuum on the face of the dam or leave an air space between it and the water. Following are the computations for this portion of the apron:

Length of spillway, 1,250'.

Maximum discharge, 30,000 sec. ft.

$$h^{3/2} = \frac{30,000}{3.6 \times 1250} = 6.66$$

h = 3.54' Maximum head over crest.

Consider 1 ft. length of spillway.

$\frac{30,000}{1,250} = 24$ sec. ft. discharge.

$\frac{24}{3.5} = 6.86$ ft. per sec., average velocity.

Since 30,000 sec. ft. is taken as the maximum flood discharge and since the discharge varies as the three halves power of the head, 6.86 ft. per sec. will be the maximum average velocity of the water flowing over the crest of the dam.

Water freely falling with an initial horizontal velocity will theoretically describe a parabola, the equasion of which is of the form $x^2 = cy$.

In the case under consideration -

$x = vt = 6.86t$

$y = \frac{1}{2}gt^2 = 16.1t^2$

Substitute these values in the equasion $x^2 = cy$.

$6.86^2 t^2 = c16.1t^2$

$6.86^2 = 16.1c$

$c = \frac{6.86^2}{16.1} = 2.92$

The equasion of the curve is $x^2 = 2.92y$.

The Bucket. The function of this portion of the dam is to change the direction of the water from its freely falling direction to a direction parallel with the stream bed. It is also advantageous to give the water a slight upward direction before leaving the dam to lessen the liability of scouring the bed

of the stream at the toe of the dam and thus undermining and endangering its stability. To this end the parabola is continued to a point about 6' below the crest, at which point it runs into a tangent about 5' long, which joins on to a curve which is a portion of a circle 4'6" radius. This curve continues downward and outward until it is tangent with a horizontal line where it is given a slight upward curve to give the water the slight upward direction referred to.

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SELECTION OF THE TURBINES:

Power Units. In a low and variable head development such as the one under consideration, a careful selection of the turbines is very important. Frequently special designs are made with a view to keeping the efficiency as high as possible over a wide range of head which, in the case in hand, may vary from 16' to nearly zero in times of high water. Before a turbine is installed in such a low head development, it should be put through efficiency tests under the same conditions as it will actually encounter during operation, with varying speeds and heads. From the data to be obtained by such a series of tests, characteristics curves of the turbine can be constructed. Taking into consideration the head at the plant during the major portion of the year, the speed for highest efficiency could be determined from these curves and the electrical equipment designed accordingly.

It is desirable to have a fairly high turbine speed, since the generators are to be directly connected. It will be also desirable to have the power output from as few machines as possible for, as a rule, larger machines are more efficient. These requirements call for a wheel with a large value of K_5 ($K_5 = \frac{n^3 P}{h}$) A special 123" turbine made by the Allis-Chalmers Co. designed for a 14' head at 64.3 R. P. M. to develop 1000 B. H. P. had a value of K_5 equal to 6780, which was larger than that of any other turbine investigated. However, tests under variable speeds and heads for this turbine have not been made or were not available.

so that the most efficient speed for an average head of 15' could not be determined. Standard generators to run at a speed of 64.3 R. P. M. were used, so turbines of the same proportions as the above Allis-Chalmers special turbine, but of different diameters were selected to operate under a maximum head of 16' at 64.3 R. P. M.

DETERMINATION OF THE DIAMETER:

$$\frac{P}{D^2 \times h^{3/2}} = K_2 = .00142$$

Neglecting the small variation in Ø:

$$D^2 = \frac{1000}{16^{3/2} \times .00142} = 11100 \quad \therefore \quad D = 105''$$

Eight power units will be installed, and provision made for the installation of two more.

Exciter Units. Two exciter units will be installed and provision made for the installation of a third. These exciter units will operate at 120 R. P. M. to develop 250 B. H. P. at 16' head. One of these exciter units is sufficient to excite the power units for a limited time under full load.

$$K_5 = \frac{120 \times 250}{16^{5/4}} = 3510.$$

A "Sampson" turbine manufactured by ~~the~~ James Leffel & Company has a value of K_5 equal to 3833. The value of K_2 for the same turbine is equal to .00159.

$$K_2 = \frac{250}{D^2 \times 16^{3/2}} = .00159.$$

$$D^2 = \frac{250}{16^{3/2} \times .00159} = 2460.$$

$$D = 49.6 \quad \text{Say } 50''$$

OPERATION.

The chief feature of interest in the operation of the plant from a hydraulic standpoint is the fact that the discharge of surplus water over the dam will be separated from the discharge from the turbines by a wall running parallel with the Desplaines River to the Kankakee River. This surplus flowing into the Kankakee River joins the tailwater from the turbines about 1,000' below the powerhouse. This give the tailwater from the turbines a freer opportunity to flow away (there is a slope of 1½" to 1,000' in the bed of the stream below the powerhouse) and will increase the head.

It might be advantageous to use flash-boards, but considering the extreme length of the spillway their use would be attended with difficulties. Should it be considered advisable to use them they could be designed to be operated from the interior of the dam.

BACKWATER CONDITIONS.

During normal stages the building of the proposed dam will permanently inundate approximately acres of bottom land. The 515' contour on the map to be found in the back of this thesis approximately marks the limit of the new water level during normal stages. This land is worthless for agricultural purposes unless drained and is subject to the semi-annual inundations at flood times. During flood periods the presence of the dam would accentuate backwater conditions but little. With a depth of water flowing over the dam equal to 3.54', which provides for the maximum flood conditions of 30,000 sec. ft., the dam would act as a submerged weir and the head at the dam site would be practically destroyed. This condition is made possible by the extreme length of the spillway and while it has the disadvantage of decreasing the head greatly during high water, this disadvantage is necessary for the densely populated Desplaines Valley prohibits extreme flood conditions. Moreover it is understood that a project such as the ones with which this thesis deals is feasible only when it is a factor in an inter-connected system of steam and hydro-electric generating plants.

Power House

The building is to be 355 ft. long and 70 ft. wide, inside dimensions, and constructed of brick, concrete and steel. The distance between the roof girders and the main floor will be 48 ft.

The foundation and tail raceis made entirely of concrete. The outer walls (which were not calculated) are of common red brick, while the inside walls are of white terra cotta brick. All window and door frames are of the pressed steel construction and will be of the standard size for use in power house buildings.

The generator and the turbine room is partitioned off by a brick wall running parallel to the length of the power house. This leaves a space 30 ft. wide for the units. In this space is a 30 ton motor-operated crane, 30 ft. above the main floor level. The remaining space will contain the transfer busses, form K2 switches, transformers, repair shop and an office.

The form K2 switches, transfer bus and the transformers will be on the main floor on the side of the building. The repair shop and office will be on the main floor, at the north end of the building.

The second floor is made of concrete spanned with 8 inch I beams placed every 11 feet along the length of the power house. On this floor is form H_3 motor operated

oil switches for the generators and also the operating bench board for the generators and exciters.

The third floor is constructed the same as the second ~~floor~~ and is the high tension floor, in which is located the high tension busses, sectionalizing busses, and three form H3 motor operated switches used for three outgoing lines. This third floor does not extend the whole length of the power house, but stops at a distance of 30 ft. from the north end of the building. In this space is located the lightning arresters.

Electrical Equipment.

The alternating current generators are direct connected to vertical inflow, reaction type, single discharge water wheel units made by the Allis Chalmers Co. The total capacity of the plant will supply ten units, eight of which are to be installed when the power house is built, the remainder when the output of the station demands them. The generators are rated at 6600 volts, 60~, 64 1/3 R.P.M. revolving field units rated at 1000 HP each.

The exciters are three in number, two to be installed when the power house is built and the third when the remaining generators are installed. The exciters are rated at 250 HP, 120 R.P.M., 125 volts and are direct current compound generators.

The 6600-volt output is stepped up to a transmission

voltage of 66,000 volts by three, single phase, 250 K.V.A., General Electric transformers, oil insulated, water cooled. The low and high tension sides are connected closed delta.

The 6600 volt bus is equipped with a form K2 oil switch and a transfer bus, the 66000 volt bus is equipped with two form H3 motor operated oil switches for each generator. The leads from the generators are equipped with instrument transformers for switchboard equipment.

They are insulated from the walls by General Electric wall insulators. From the 66000 volt bus there are three independent lines, Each goes through a form H3 motor operated switch, disconnect switches, choke coil and separate wall outlets to the line. The lines are protected by General Electric aluminium-cell lightning arresters with horn gaps located above the cells.

The operating bench-board is composed of thirteen panels, one for each of the generators and exciters. It is of the standard bench board type made by the General Electric Company.

Transmission Line Calculations.

Data.

1. Power generated = 7500 K.W. at unity power factor.
2. Frequency = 60 cycles.
3. Number of phases = 3.
4. Distance = 50 miles.
5. Number of wires = 9.
6. Voltage at receiver end of line = 64000
7. Economic drop = 3.03%.
8. Resistance per wire = 2/0-33 ohms, #1 - 50 ohms.
9. Kind of wire = aluminum.
10. Size of wire = #2/0 and # 1 B&S.
11. Distance between wires = 72 inches.
12. Inductance per wire = 0.0905 henrys.
13. Capacity per wire = 0.845 microfarads.
14. Charging current per conductor = 5. 06 amperes.
15. Natural frequency = 640 cycles.
16. Regulation = 2. 89%
17. Point at which corona will begin = 2½ feet.
18. Distance between towers = 660 feet.
19. Conductor weight per tower including ice = 3780 lbs
20. Sag at maximum temperature = 3.73 feet.

Economic Drop.

Let E = voltage at generator station = 66000

P = power " " " in K.W. = 7500

L = length of line in miles = 50.

R = total resistance of line in ohms.

X = loss in terms of impressed quantities.

S = section of conductor in circular mils.

C_1 = cost of energy in dollars per K.W. year at gen. station = \$25.

C_2 = cost of conductor in dollars per pound = \$.27 for Al. = \$.15 for Cu.

P_2 = interest rate on cost of line conductor = 9%

K_1 = resistance in ohms per mile of conductor having one circular mil cross-section = 85,000 ohms.

K_2 = Wt. in pounds per mile of conductor above = 0.0048

$$K = p_2 c_2 K_1 4 \cdot L_1^2 \cdot 1000 \cdot K_2$$

$$= .09 \times .27 \times 85000 \times .0048 \times 4 \times 50^2 \times 1000$$

$$= 99,250,000$$

$$X = -\frac{3}{4} \times \frac{K}{E^2 C_1} \quad \frac{1}{4 E^2 C_1} \times \sqrt{9K^2 + 12 E^2 C_1 K}$$

$$= -\frac{3}{4} \times \frac{99250000}{66000^2 \times 25} + \frac{\sqrt{9 \times 99250000^2 + 12 \times 66000^2 \times 25 \times 99250000}}{4 \times 66000^2 \times 25}$$

$$= 0.0303$$

Economic drop = 3.03%

$-\frac{7500}{3} \times .0303 + \frac{7500}{3} = 2425$ K.W. supplied at receiver by each of the three seperate lines in winter.

$-\frac{7500}{2} \times .0303 + \frac{7500}{2} = 3636$ K.W. supplied at receiver by each of the two lines in summer.

$$S = \frac{1}{2}\left[\frac{1000P}{E^2} \times K_1 \times \frac{2L_1}{X}\right]$$

$$= \frac{1}{2}\left[\frac{1000 \times 3750}{66000^2} \times 85000 \times \frac{2 \times 50}{.0303}\right]$$

$= 120{,}500$ cir. mils.

$= 2/0$ B&S wire.

Area $= 133{,}100$ cir. mils $= 0.105$ sq. inches.

This wire is to be used as the lower 6 conductors, and are to carry the total load during the summer.

$$s = \frac{120500}{3750} \times 2500$$

$= 80{,}500$ cir. mils.

$=$ #1 B&S. wire.

$= 83{,}690$ cir. mils $= 0.066$ sq. inches.

This wire is to be used as the ground wire in summer and to carry a part of the load during the winter.

Resistance per wire.

For the 2/o wire

$= 50 \times 0.66$

$= 33$ ohms.

For the #1 wire.

$= 50 \times 1.$

$= 50$ ohms.

Corona.

$$Em = g\,r \log_e \frac{R}{r}$$

$$\sqrt{2} \times 66000 = 100000 \times .182 \times \log_e \frac{R}{.182}$$

$$\text{Log}_{10} \frac{R}{.182} = \frac{\sqrt{2} \times 66000}{100000 \times .182 \times 2.303}$$

$$= 2.222$$

$$\frac{R}{.182} = 167$$

$R = 30.4"$
$= 2\frac{1}{2}$ ft. distance at which corona will form.

Inductance , approximately only.

o o o

o o o

o o o

$$\text{Av. } L = \left[740 \log_{10} \frac{D}{R} + 111.2\right] 10^{-6}$$ henrys per wire per mile.

$$= \left[740 \log \frac{72}{.365} + 111.2\right] 10^{-6}$$

= .00181 henrys per conductor per mile

$L = 50 \times .00181 = 0.0905$ henrys per conductor.

Capacity, approximately only.

$$C = \frac{.0388}{\log \frac{D}{R}}$$ microfarads per mile.

$$= \frac{.0388}{2.2956} \times 50$$

= . 845 microfarads between neutral and conductor.

Regulation.

E = voltage at receiving end of line.

$= 66000 [1 - .0303]$
$= 64000$ volts

$$\text{Regualtion} = \frac{\frac{E_g}{\sqrt{3}} - \frac{E}{\sqrt{3}}}{\frac{E_g}{\sqrt{3}}} \times 100 = \frac{\frac{66000}{\sqrt{3}} - \frac{64000}{\sqrt{3}}}{\frac{66000}{\sqrt{3}}} \times 100$$

$$= 2.89\%$$

Charging current.

$$I = 2\cdot\pi\cdot f\,\frac{E}{\sqrt{3}} \times C \times 10^{-6}$$

$$= 2\cdot\pi \times 25 \times \frac{66000}{\sqrt{3}} \times 0.845 \times 10^{-6}$$

= 5.06 amperes per conductor.

Sag of Conductor.

Weight per foot of the # 2/0 wire = .4028 x.3 = .1208#

Weight of ½ inch of ice on this wire is

$$\frac{\pi\left[\left(1+\frac{.365}{2}\right)^2-\left(\frac{.365}{2}\right)^2\right]}{144} \times 1 \times 57$$

= 0.55 lbs. per ft. of length.

Wt. of one cu. ft. of ice = 57#

Weight of cable and ice

$= W = .1208 + .55$

$= .671$ lbs. per foot of wire.

Wind pressure on the ice covered wire at 15 # per sq. ft. of projected area.

$$= 15 \times (1 + .365) \times \frac{1}{12}$$

= 1.72# per foot of wire.

Resultant of the weight and wind pressure

$$= W_r = \sqrt{0.671^2 + 1.72^2}$$

= 1.84# per foot

Wind pressure on wire without ice

$$= \frac{.37}{12} \times 15 \times 1 = 0.463 \text{ \# per ft.}$$

$$W_r = \sqrt{0.671^2 + 0.463^2}$$

= 0.816 # per ft.

Let length of span = 660 ft.

Distance between wires = 72"

$S_1 = 660$

$\bar{W} = 0.671$

$W_r =$ 1.84 with ice

$=$ .816 without ice

$A \doteq .105$

$T = 14000 \times \pi \left(\frac{.365}{2}\right)^2 = 1470\#$ allowable load on wire.

$t = 0, 75, 150$ temp. in degrees F. above the minimum

(-40)

k = temp. coefficient of linear expansion per degreeF.

$= 0.0000128$

$E_1 =$ stretch modulus of elasticity in lb. inch units

$= 9{,}000{,}000$

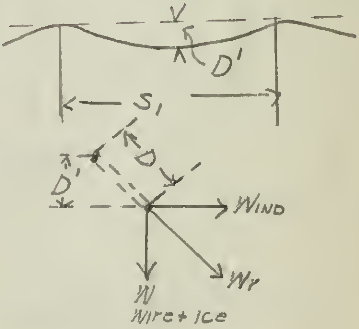
Ls = length of single span of strung cable at the min. temp. in feet.

Lu = length of unstressed single span of cable at min. temperature.

For lower range of temperatures with ice.

$$Ls = S_1 + \frac{S_1^3 \times W_r^2}{24\ T^2}$$

$$= 660 + \frac{660^3 \times 1.84^2}{24 \times 1470^2}$$



$= 678.75$ ft.

$$Lu = \frac{Ls}{1 + \frac{T}{E_1 A}}$$

$$= \frac{678.75}{1 + \frac{1470}{.105 \times 9000000}}$$

$= 677.73$ ft.

For the higher range of temperature without ice

L s = 661.39 ft.

L u = 660.36 ft.

D′ = sag in ft.

$$D^3 + \frac{3S_1}{8}\left[L\,u\ (1 + kt) - S_1\right] D = \frac{3 \times S_1^3 \times Lu \cdot W}{64\,A\,E_1}$$

$t = 0$

$$D^3 - \frac{3\times 660}{8}\left[677.73\,(1) - 660\right] D = \frac{3\times 660^3\times 677.73\times 1.84}{64\times 0.105\times 9{,}000{,}000}$$

$$D^3 - 4380D = 17850$$

$$D = 68.4 \text{ ft.}$$

$$D' = \frac{DW}{Wr}$$

$$= \frac{68.4 \times 0.671}{1.84}$$

$= 24.9$ ft at 40°F.

$t = 72$

$$D^3 - \frac{3\times 660}{8}\left[677.73\,(1 + .0000128 \times 72) - 660\right] D = 17850$$

$$D^3 - 45400D = 17850$$

$$D = 69.4 \text{ ft.}$$

$D' = 25.3$ ft at 35° F. with ice.

$t = 70$ no ice.

$$D^3 - \frac{3\times 660}{8}\left[660.36 \times (1 + .0000128 \times 70) - 660\right] D = 7700$$

$$D^3 - 235\,D = 7700$$

$$D = 23.7$$

$$D' = \frac{23.7 \times .1208}{.816}$$

$= 3.5$ ft.

$t = 150$

$$D^3 - \frac{3\times 660}{8}\left[660.36(1 + .0000128 \times 150) - 660\right] D = \frac{3\times 660^3 \times 660.36 \times 0.816}{64 \times 0.105 \times 9000000}$$

$$D^3 - 326\,D = 7700$$

$$D' = \frac{25.1 \times .1208}{.816}$$

$= 3.73$ ft. at 110° F.

Actual height of tower to lower wire $= 25.3 + 20 = 50$ft/

Forces on towers.

Force due to wt. of line conductors and ice.

= 6 x 660 x 0.671 + 3 x 660 x .568

= 3780 lbs.

Pressure due to wind. Ice on cable.

= 6 x 660 x 1.72 + 3x 660x 1.61.

= 6800+3190

= 9990 lbs.

Assume wt. of tower as 3000 lbs.

" 30 sq. ft. normal surface exposed to wind.

Wind pressure on tower

= 30 x 30 = 900 lbs.

Assume 450 lbs of this acts at top of tower.

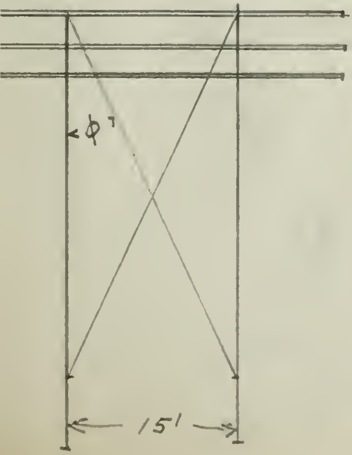
Total downward force

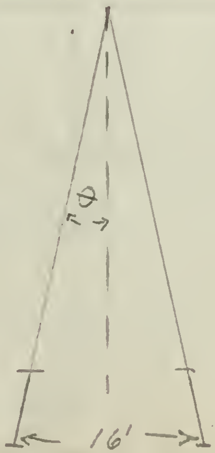
= 3780 + 3000 = 6780 lbs.

Horizontal force at top of tower

= 450 + 9990 = 10440 lbs.

Details of tower.





$\frac{8}{66} = \tan \phi$

$\phi = 6^{0}\ 55'$

Compression

Stress in main leg due to downward pressure

$$= \frac{6780}{2} \times \frac{1}{\text{Cos } 6^{\circ}\ 55'}$$

$= 3410$ lbs.

Stress in main leg due to horizontal force.

$$= \frac{10440}{2} \times \frac{1}{\text{sin. } 6^{\circ}\ 55'}$$

$= 43{,}500$ lbs.

Total compressive stress in one leg.

$= 43{,}500 + 3410$

$= 46910$ lbs.

$$\frac{46910}{\frac{27000}{2}} = 3.48 \text{ sq. in. required area for safe stres}$$

Angle iron $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{1}{2}$

Diagonal members

Angle $\phi = 12^{\circ}\ 50'$

$\frac{15}{66} = \tan \phi$

Stress in diagonal due to vertical load, compression

$$= \frac{6780}{2} \times \frac{1}{\cos 12^{\circ}\ 50'}$$

$= 3480$ lbs.

Stress due to horizontal forces, tension.

$$= \frac{10440}{2} \times \frac{1}{\text{sin. } 12^{\circ}\ 50'}$$

= 23 500 lbs.

Total stress

= 23500 -3480

= 20020 = 20000 lbs.

$$\frac{20000}{\frac{60000}{2} \times .75} = 0.89 \text{ sq. in. required}$$

Angle iron $2\frac{1}{2}$ x$2\frac{1}{2}$x 3/16"

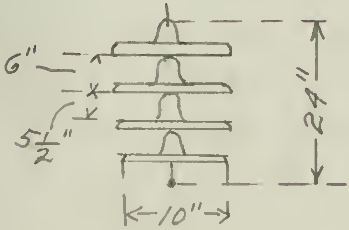
Cross arms

5" channels

Anchorage

Bed plate of 10" channel $1\frac{1}{2}$ ft long.

Insulators.



FEASIBILITY.

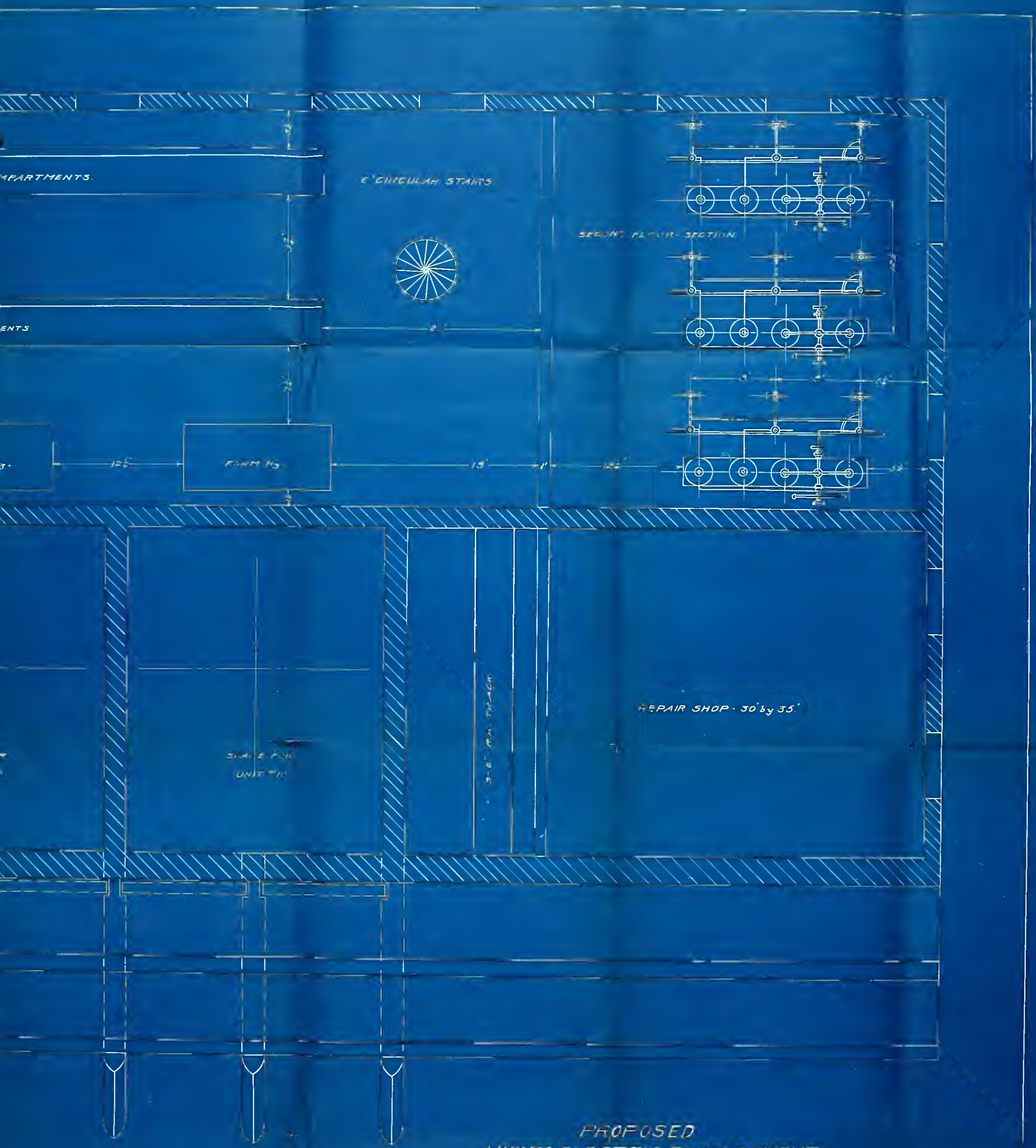
While it is beyond the scope of this thesis to investigate the necessary investment and the revenues that might be expected from the operation of this proposed development of the Desplaines River, it can be pointed out wherein lie the economies and the limitations of such a development.

The feasibility depends largely on the artificial flow from Lake Michigan through the Chicago Drainage Canal. While the natural flow will be utilized during normal stages, the extreme variations in this natural flow would be fatal to a low head development unless storage is available, or the spillway section of the dam be made relatively short, which would greatly aggravate flood conditions. As has been said before, the density of the population of the Desplaines Valley prohibits this. This development should be a unit in an inter-connected system of steam and hydro-electric generating stations or have some form of auxiliary power. The larger economics of the proposition would suggest the former course, as it has been demonstrated that the load factor is increased sometimes as much as 10% by such diversified system. As an isolated plant it would have to contend with semi-annual flood conditions in which the head would be greatly reduced, frequently beyond the point of possible operation. But as a unit in such an inter-connected system and depending on the uniform flow from Lake Michigan, the installation will develop 10,000 hp. or more

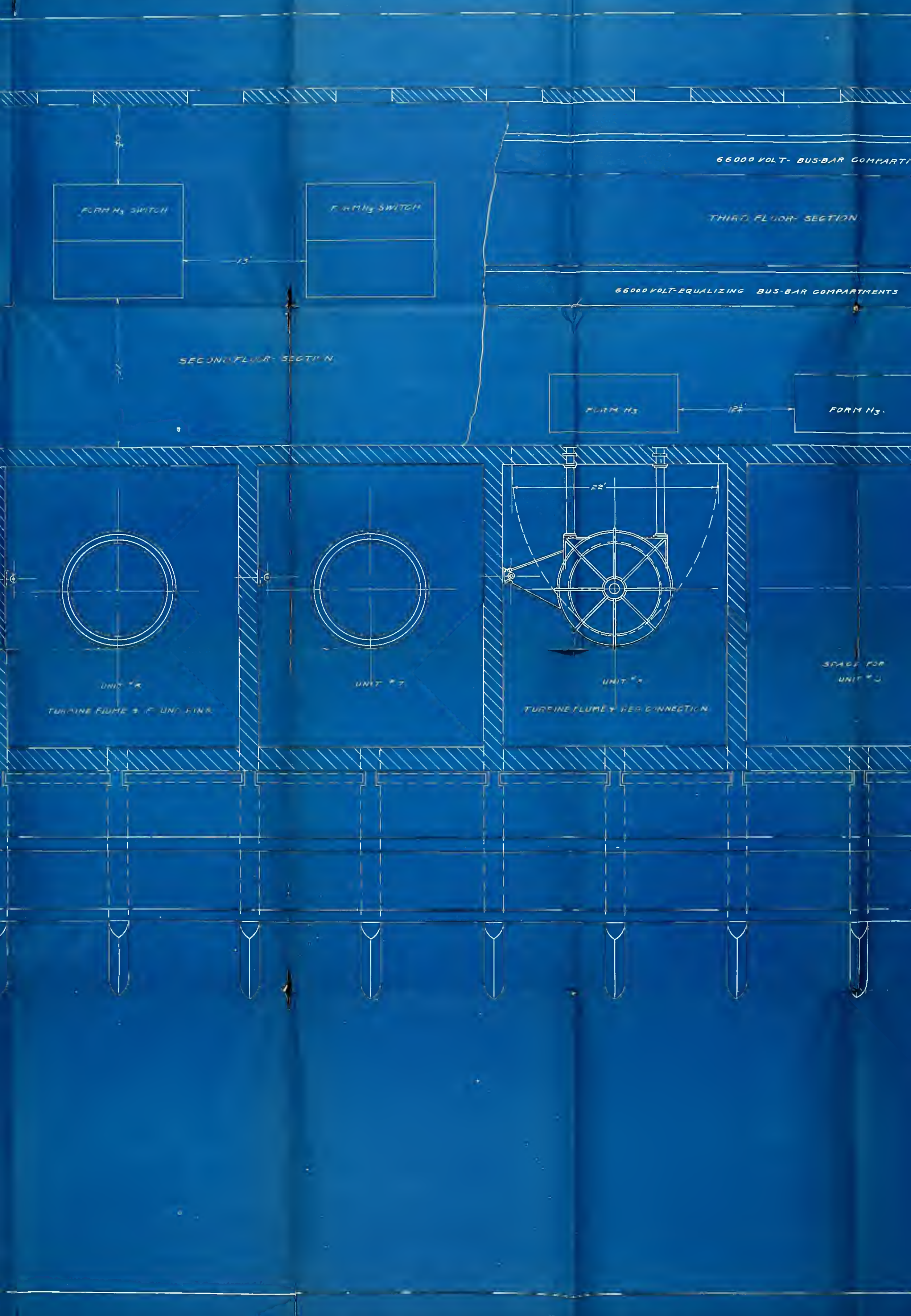
during the major portion of the year, and it is thought the development of the 16' head at this point would be economical.

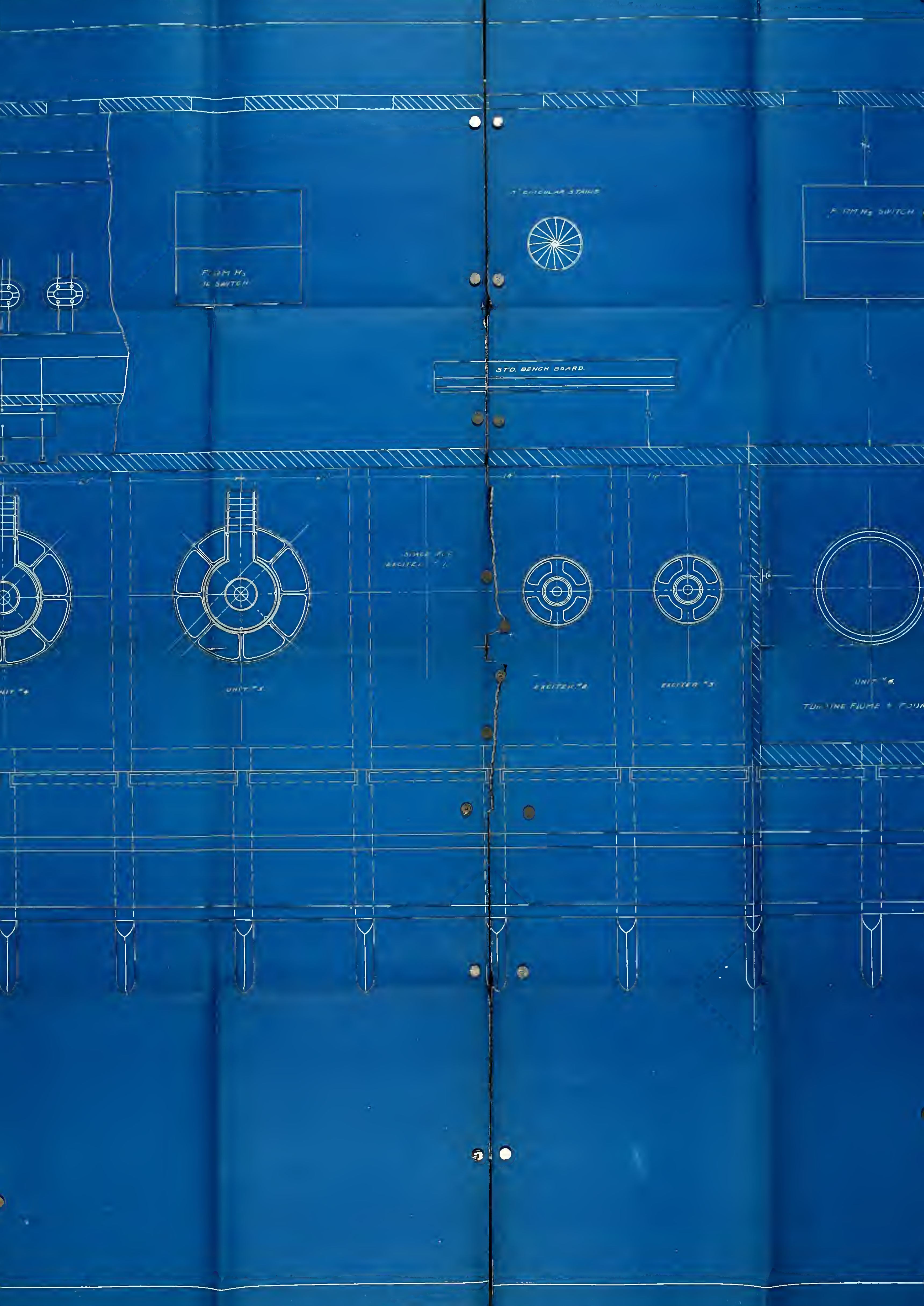
Another thing that would invalidate the proposed plans, or at least greatly change them, is the possibility of extending a deep waterway from Lake Michigan to the Gulf of Mexico. This would necessitate the building of a lock at this point or wherever it was necessary to construct the dam. It would also be necessary to excavate a channel below the dam and to maintain the backwater on the reach below at a depth sufficient for navigation. This would necessitate the building of a dam further down stream of sufficient height to extend its backwater curve to the proposed dam even during low river stages. During normal and high stages this backwater would reduce the head at the proposed dam site.

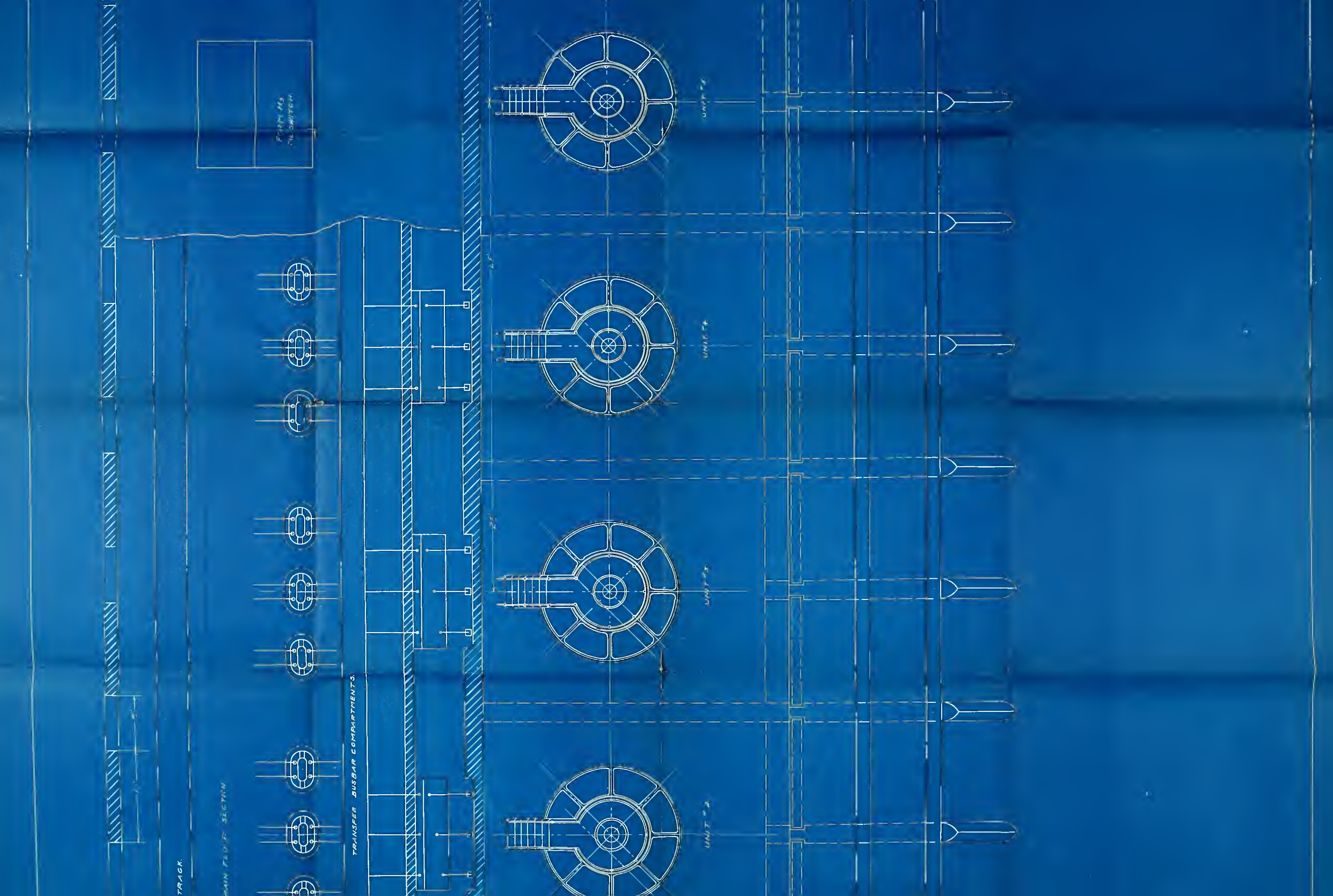
****

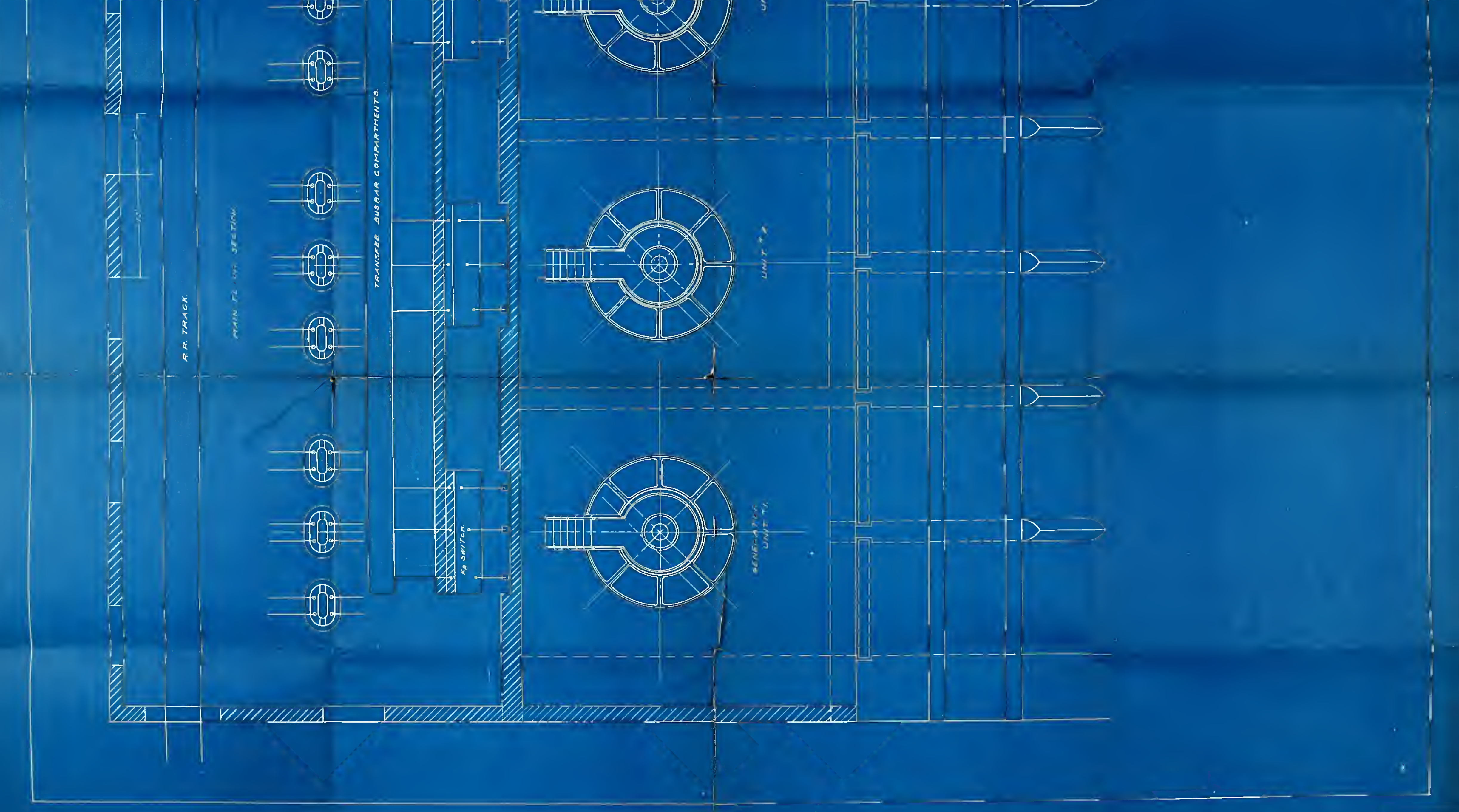


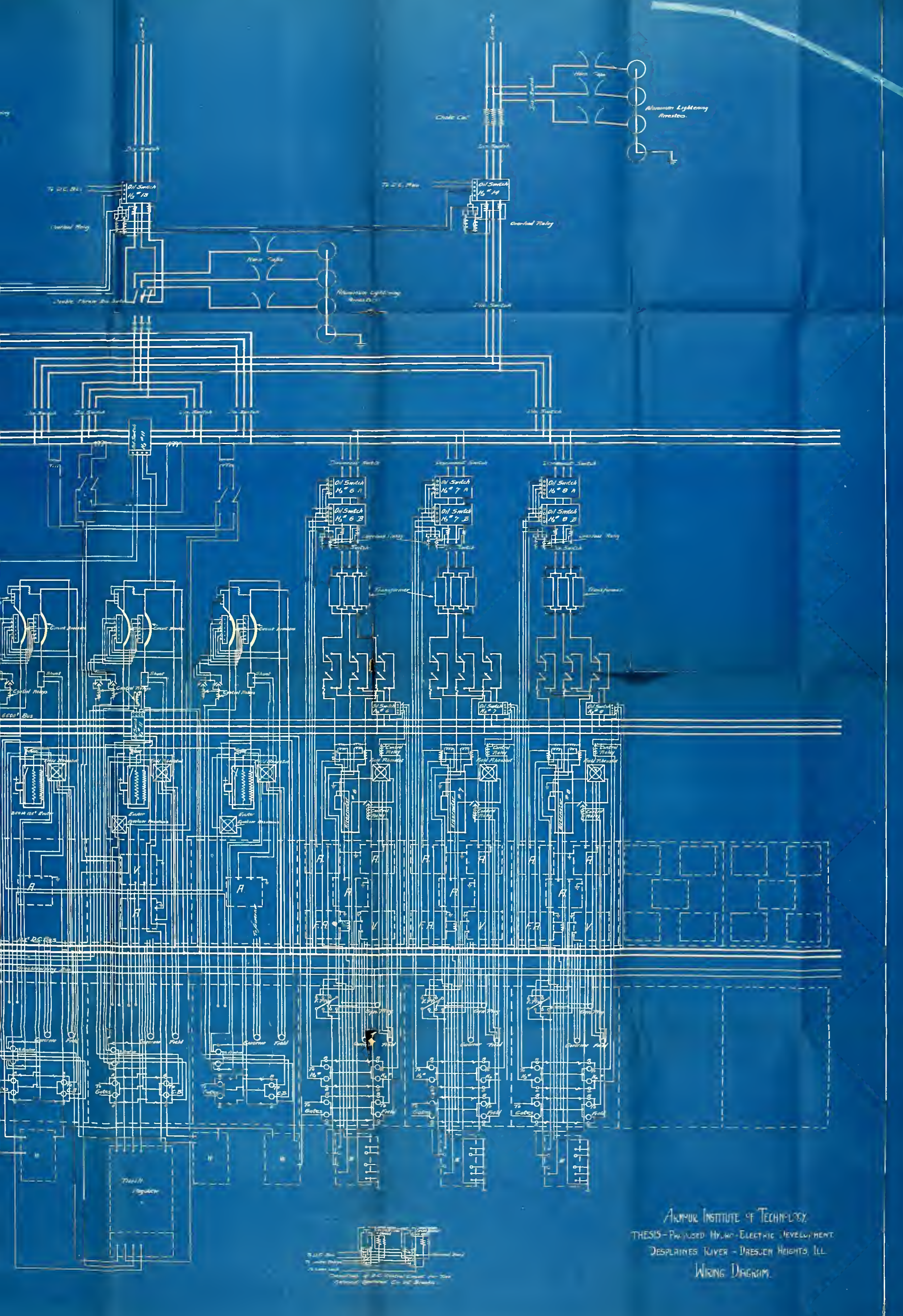
PROPOSED
HYDRO-ELECTRIC DEVELOPMENT
IN THE
DESPLAINS RIVER
ARMOUR INSTITUTE OF TECHNOLOGY
DRAWN BY [illegible] MAY 20, 1913.
TRACED BY [illegible] SCALE $\frac{1}{4}$"=1'-0"
CHECKED BY [illegible] CHICAGO, ILL.
PLAN VIEW


66000 VOLT- BUS-BAR COMPART
THIRD FLOOR- SECTION
66000 VOLT-EQUALIZING BUS-BAR COMPARTMENTS
FORM H3 SWITCH
FORM H3 SWITCH
13'
SECOND FLOOR- SECTION
FORM H3
12'
FORM H3.
22'
UNIT #8
TURBINE FLUME & FOUNDATIONS
UNIT #7
UNIT #6
TURBINE FLUME & REG CONNECTION
SPACE FOR
UNIT #5

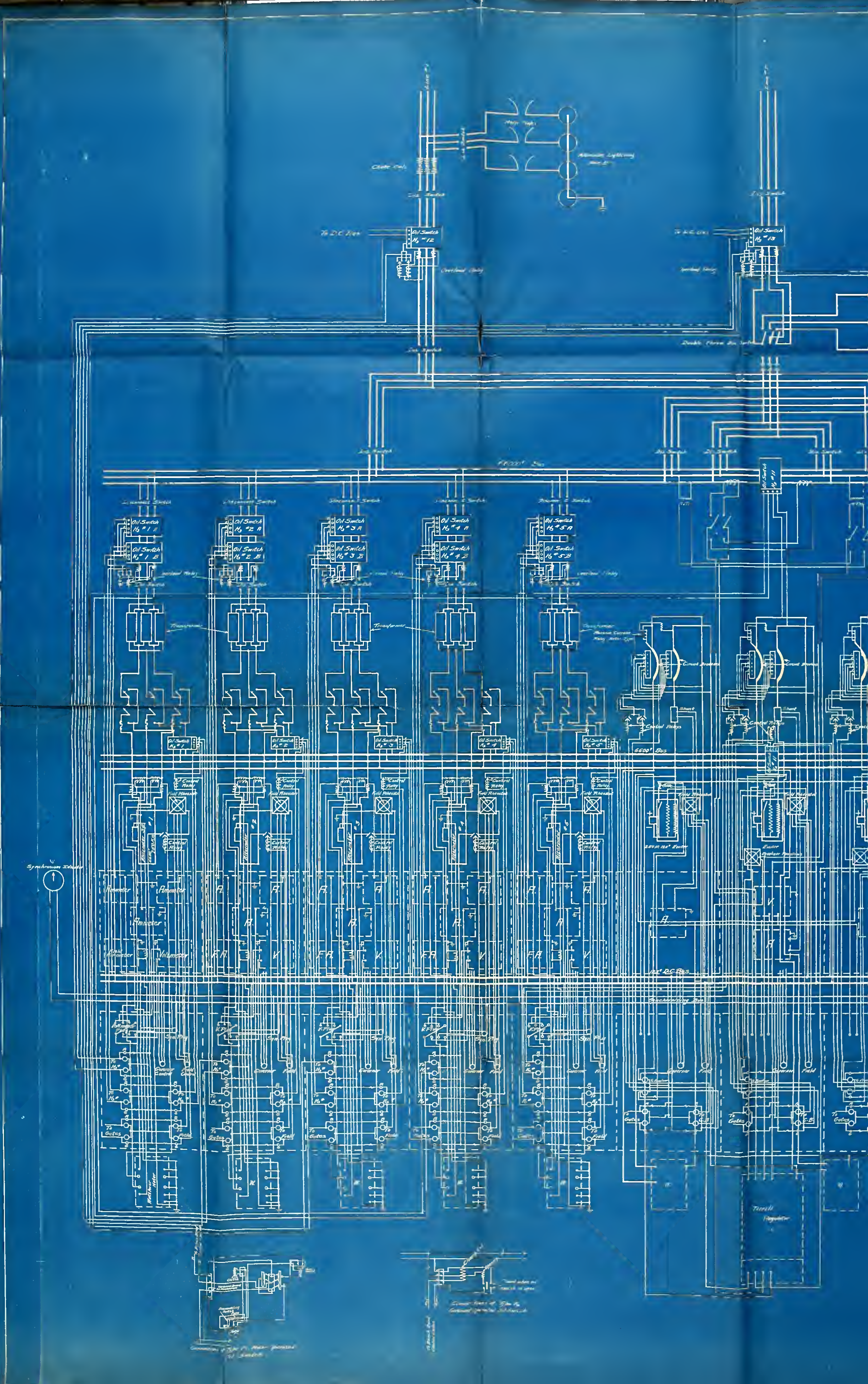

FORM H3 14 SWITCH
3' CIRCULAR STAIRS
FORM H3 SWITCH
STD. BENCH BOARD.
14'
14'
SPACE FOR EXCITER #1
UNIT #4
UNIT #5
EXCITER #2
EXCITER #3
UNIT #6.
TURBINE FLUME + FOUN


FORM H3
OIL SWITCH
UNIT #5
UNIT #4
UNIT #3
UNIT #2
TRANSFER BUSBAR COMPARTMENTS.
TRACK.
AIN FLOOR SECTION

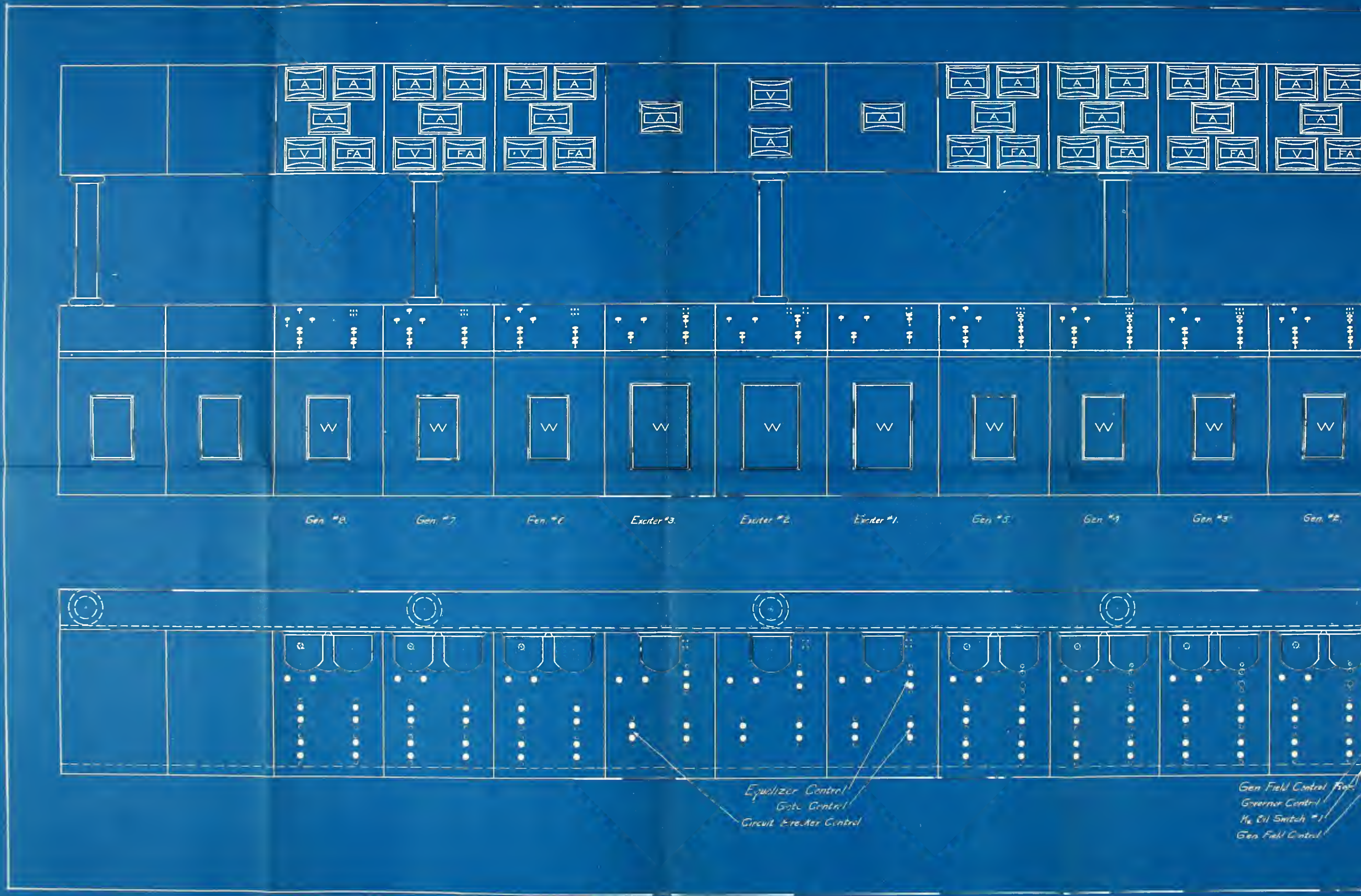

R.R. TRACK.
MAIN FL'R SECTION
TRANSFER BUSBAR COMPARTMENTS.
K2 SWITCH.
UNIT # 2
GENERATOR UNIT # 1

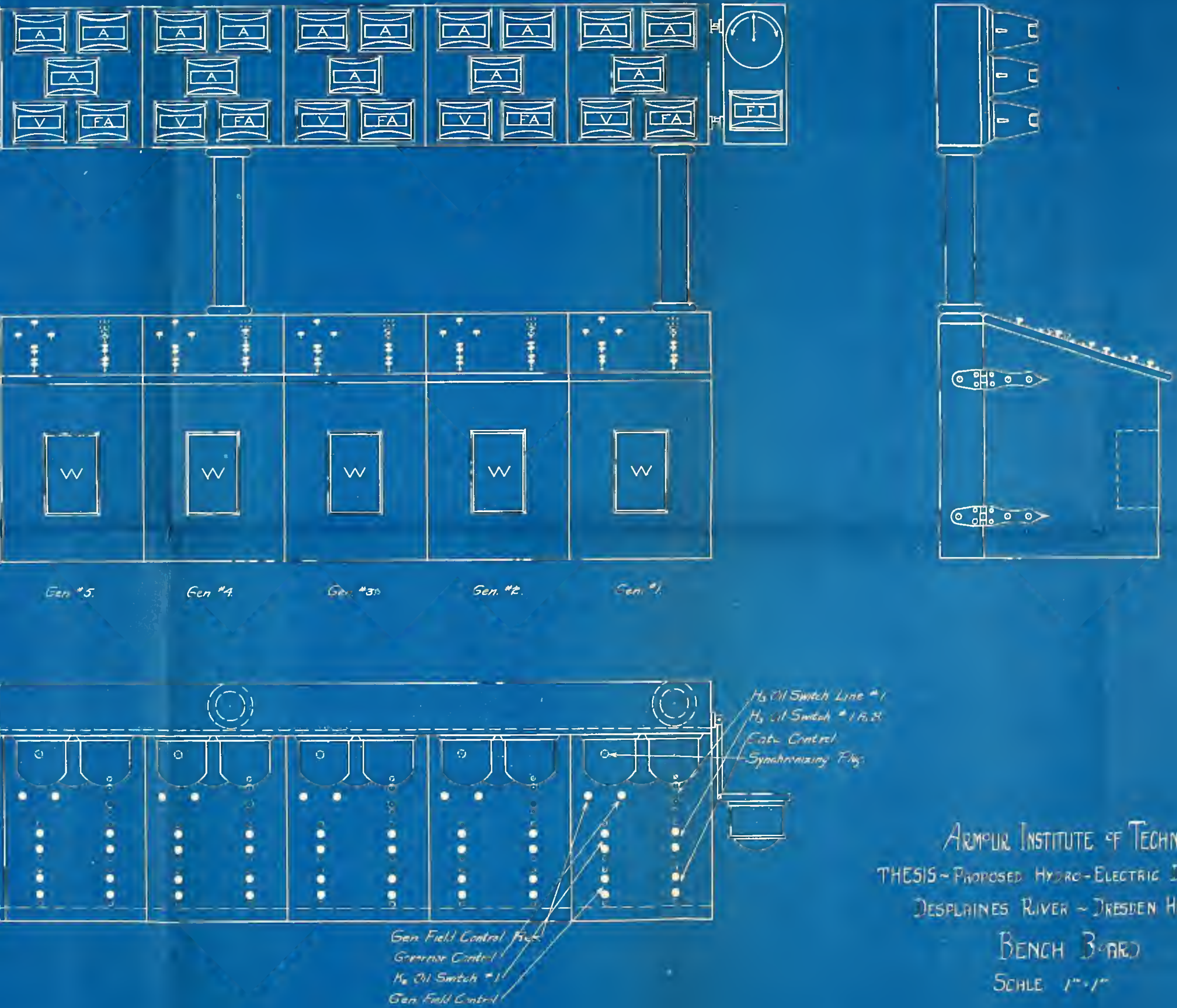


Armour Institute of Technology.
THESIS – Proposed Hydro-Electric Development
Desplaines River – Dresden Heights, Ill.
Wiring Diagram.



Choke Coils
Horn Gaps
Aluminum Lightning Arrester
Disc. Switch
To D.C. Bus
Oil Switch No 12
Oil Switch No 13
Overload Relay
Double Throw Bus Switch
Bus Switch
Disc. Switch
6600 Bus
Disconnect Switch
Oil Switch No 1 A
Oil Switch No 1 B
Oil Switch No 2 A
Oil Switch No 2 B
Oil Switch No 3 A
Oil Switch No 3 B
Oil Switch No 4 A
Oil Switch No 4 B
Oil Switch No 5 A
Oil Switch No 5 B
Oil Switch No 11
Overload Relay
Transformer
Circuit Breaker
Shunt
Control Relays
6600 Bus
Oil Switch No 1
Oil Switch No 2
Oil Switch No 3
Oil Switch No 4
Oil Switch No 5
Control Relay
Field Rheostat
250 V.125 Exciter
Exciter Rheostat
Synchronism Indicator
Ammeter
Voltmeter
A.
V.
F.A.
125 D.C. Bus
Synchronizing Bus
Syn. Plug
Governor
Field
To Gates
To Field
Watthour Meter
Tirrill Regulator


A
A
V
FA
Gen. #8.
Gen. #7.
Gen. #6.
Exciter #3.
Exciter #2.
Exciter #1.
Gen. #5.
Gen. #4.
Gen. #3.
Gen. #2.
W
Equalizer Control
Gate Control
Circuit Breaker Control
Gen Field Control Rh.
Governor Control
K₂ Oil Switch #1
Gen Field Control



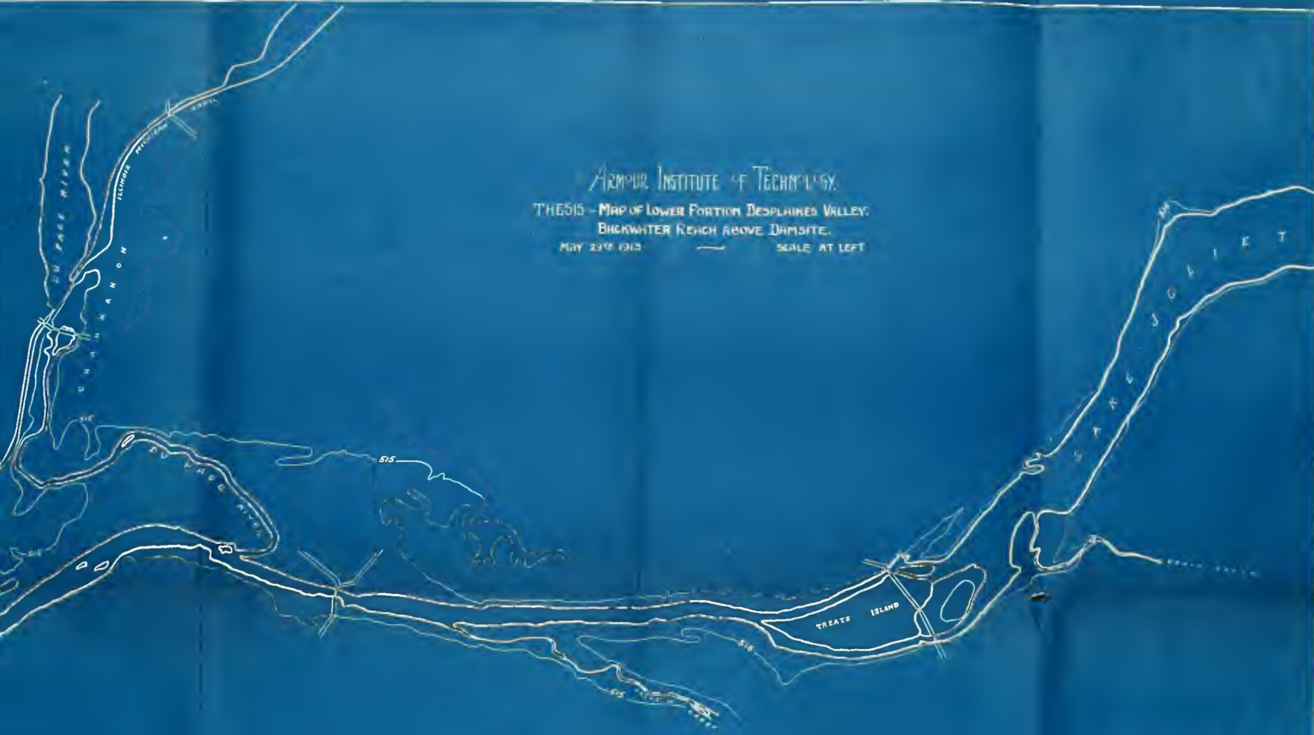
Armour Institute of Technology.
Thesis ~ Proposed Hydro-Electric Development.
Desplaines River ~ Dresden Heights, Ill.

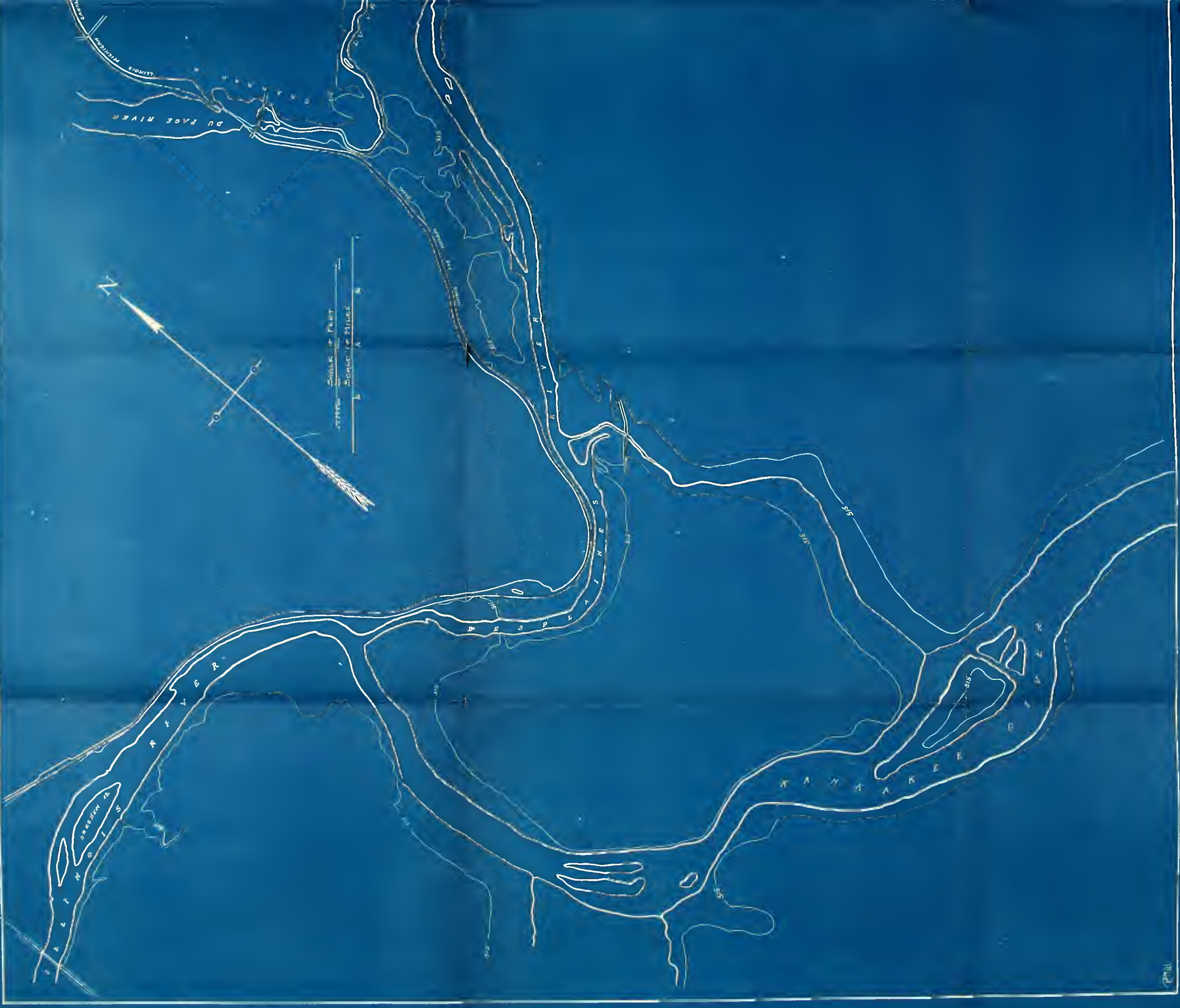
Bench Board

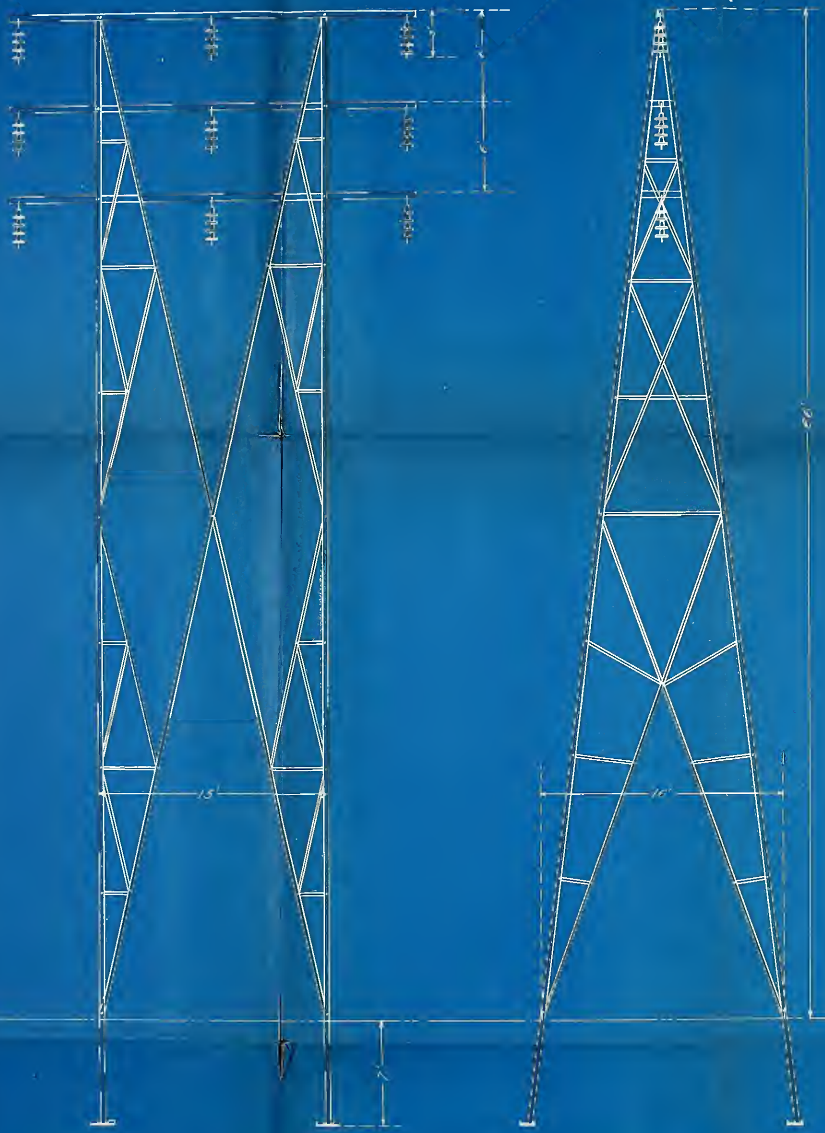
Scale 1" = 1"

ARMOUR INSTITUTE OF TECHNOLOGY.

THESIS – MAP OF LOWER PORTION DESPLAINES VALLEY:
BACKWATER REACH ABOVE DAMSITE.
MAY 23RD 1913 —— SCALE AT LEFT




ILLINOIS MICHIGAN CANAL
DU PAGE RIVER
CHANNAHON
DES PLAINES RIVER
ILLINOIS RIVER
DRESDEN IS.
KANKAKEE RIVER
N
Scale of Feet
Scale of Miles
515

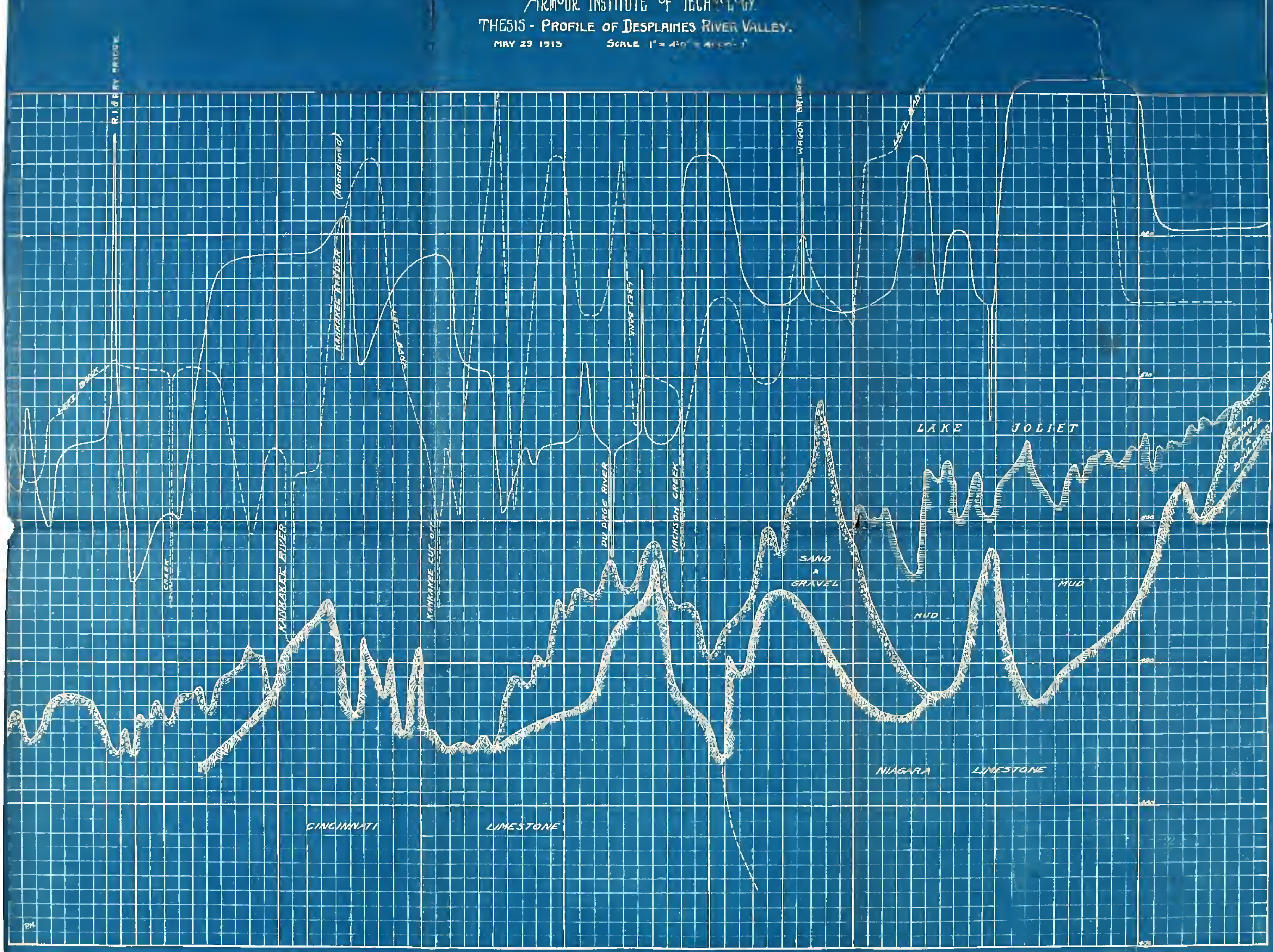


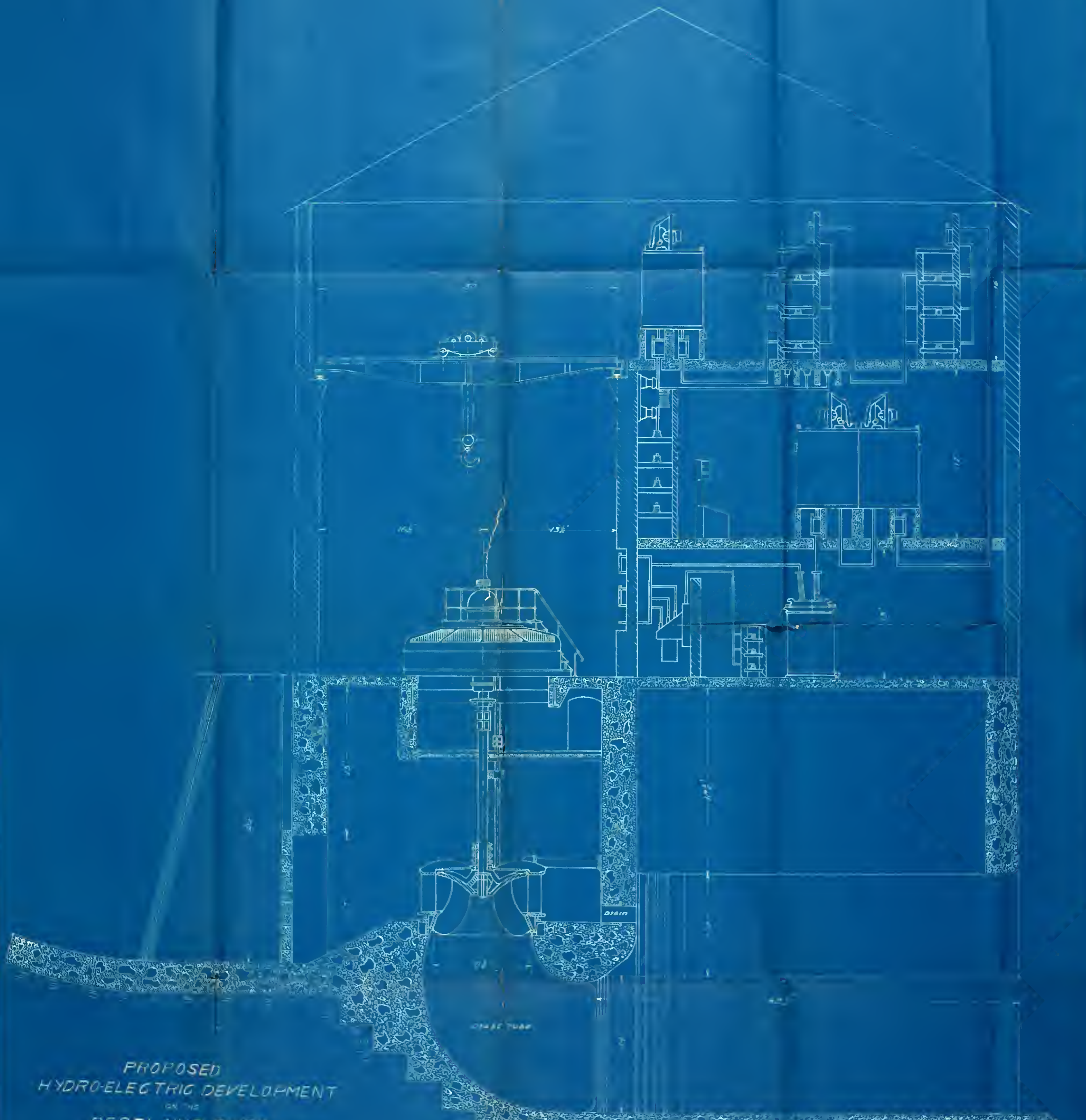
Armour Institute of Technology
THESIS - Proposed Hydro-Electric Development
Desplaines River - Dresden Heights Ill.
Transmission Tower
Scale 1" - 4'"

ARMOUR INSTITUTE OF TECHNOLOGY

THESIS - PROFILE OF DESPLAINES RIVER VALLEY.

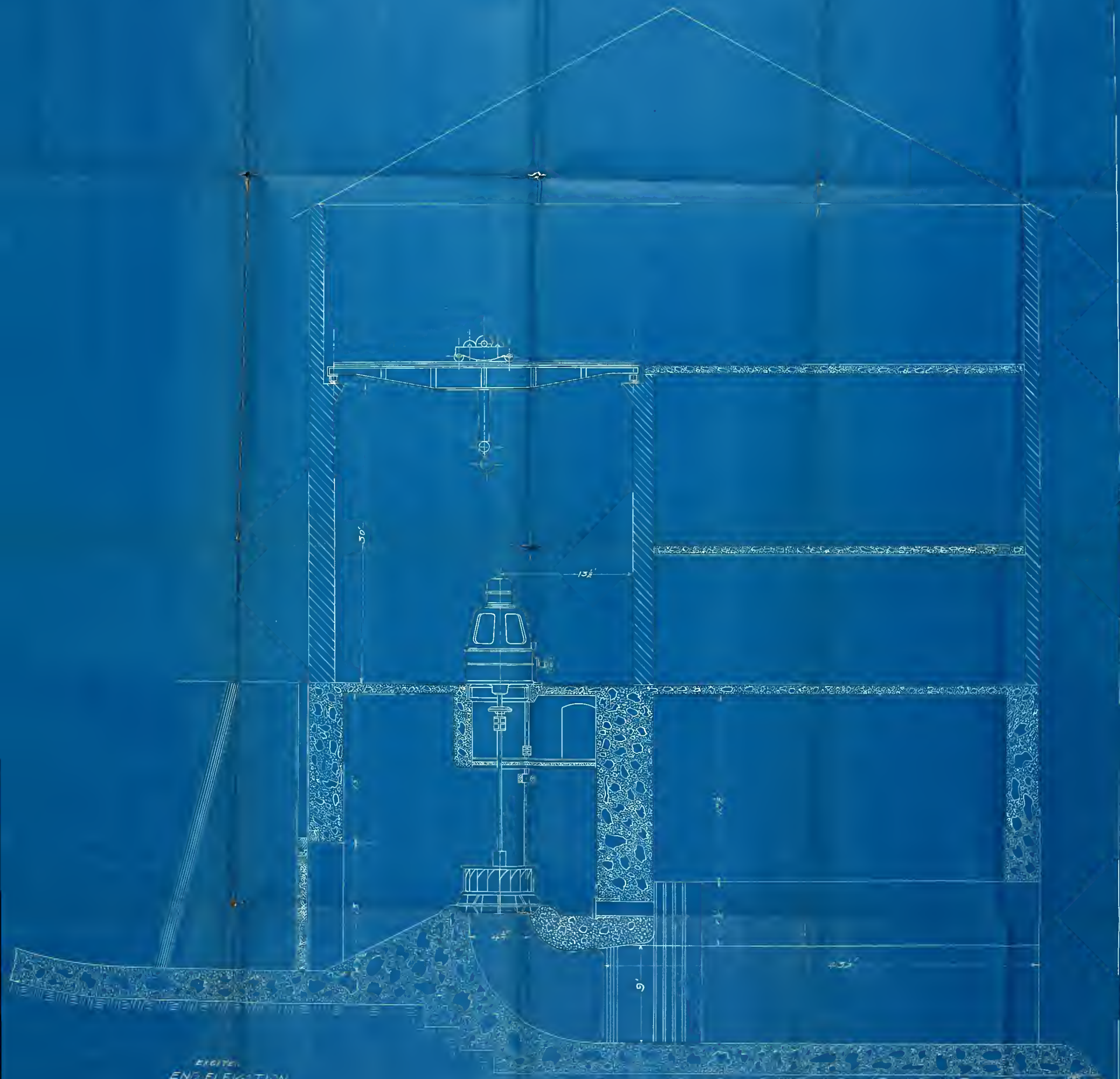
MAY 29 1913 SCALE 1" = 4'0" [illegible]





PROPOSED
HYDRO-ELECTRIC DEVELOPMENT
ON THE
DESPLAINS RIVER
ARMOUR INSTITUTE OF TECHNOLOGY
DRAWN BY [illegible] MAY 20 1915
TRACED BY [illegible] SCALE [illegible]
CHECKED BY [illegible] CHICAGO ILL

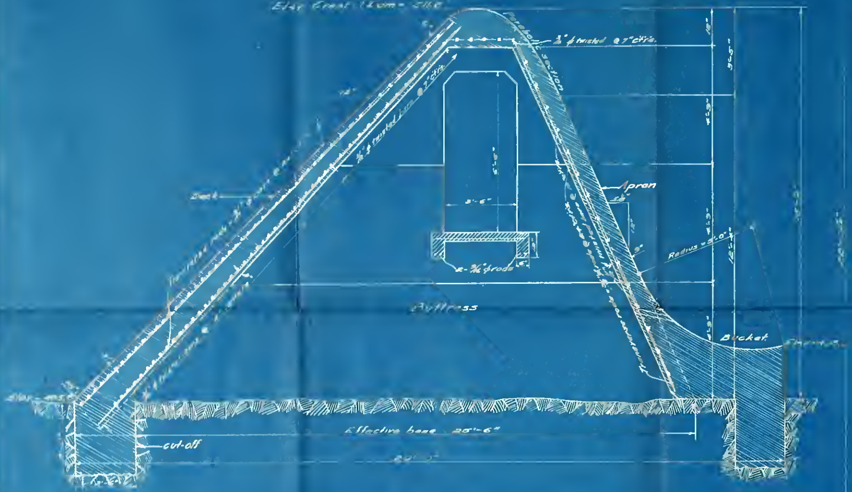
END ELEVATION



EXCITER
END ELEVATION
SCALE

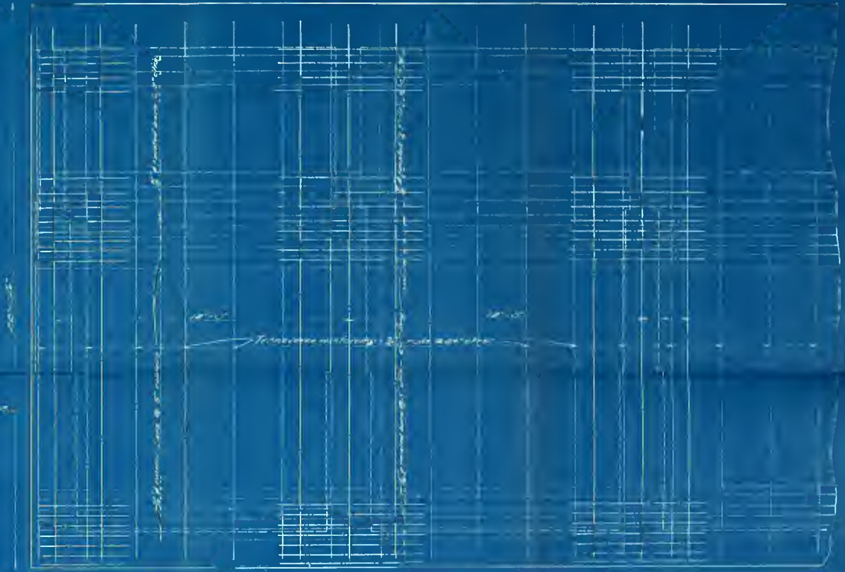
Max. Elev. High water = 5XX.X'

Typical cross section



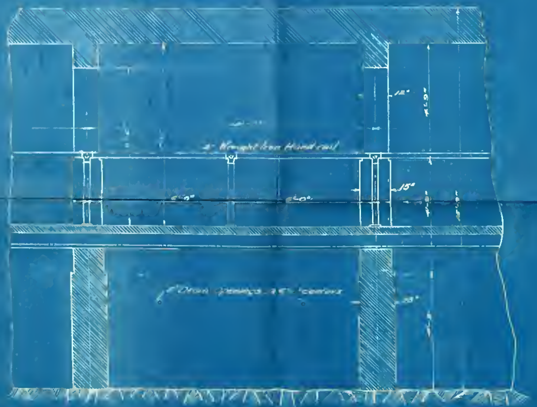
Plan view of Deck

bottom reinforcing shown by light broken lines.
top reinforcing shown by heavy broken lines

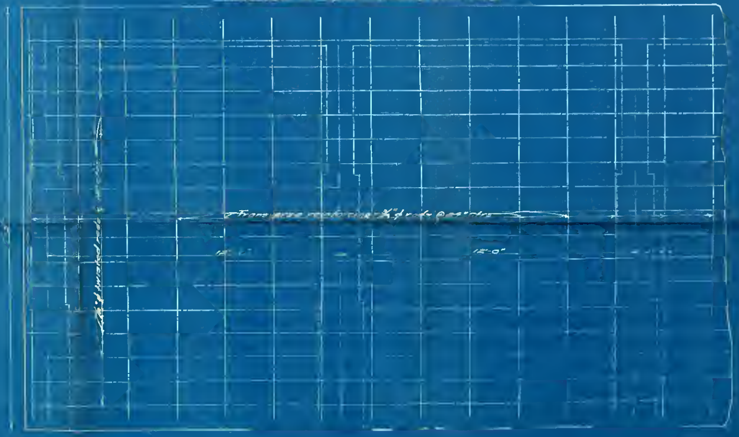


104 Panels @ 12'-0" = 1248'-0" total length of Deck

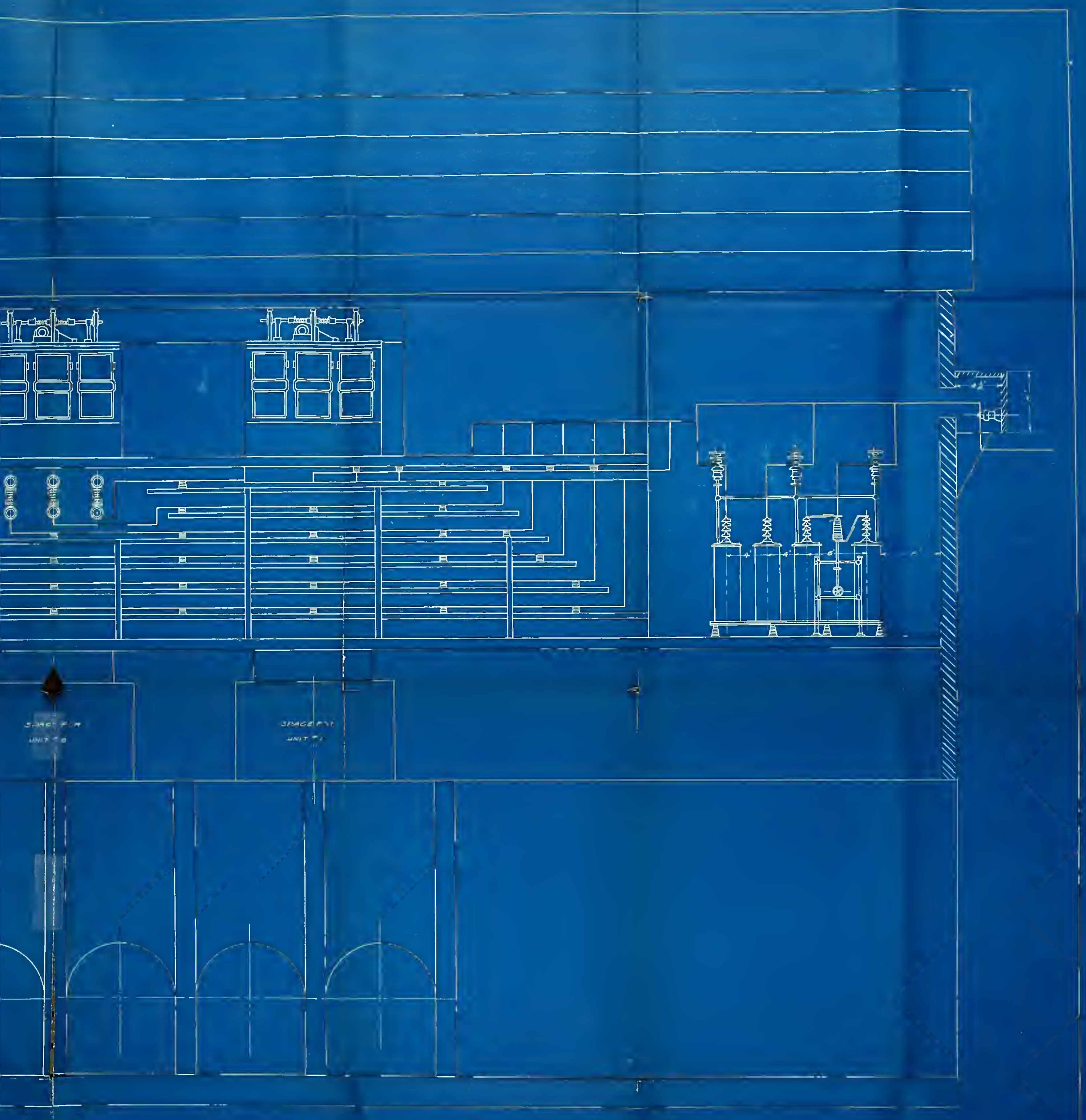
Typical longitudinal section



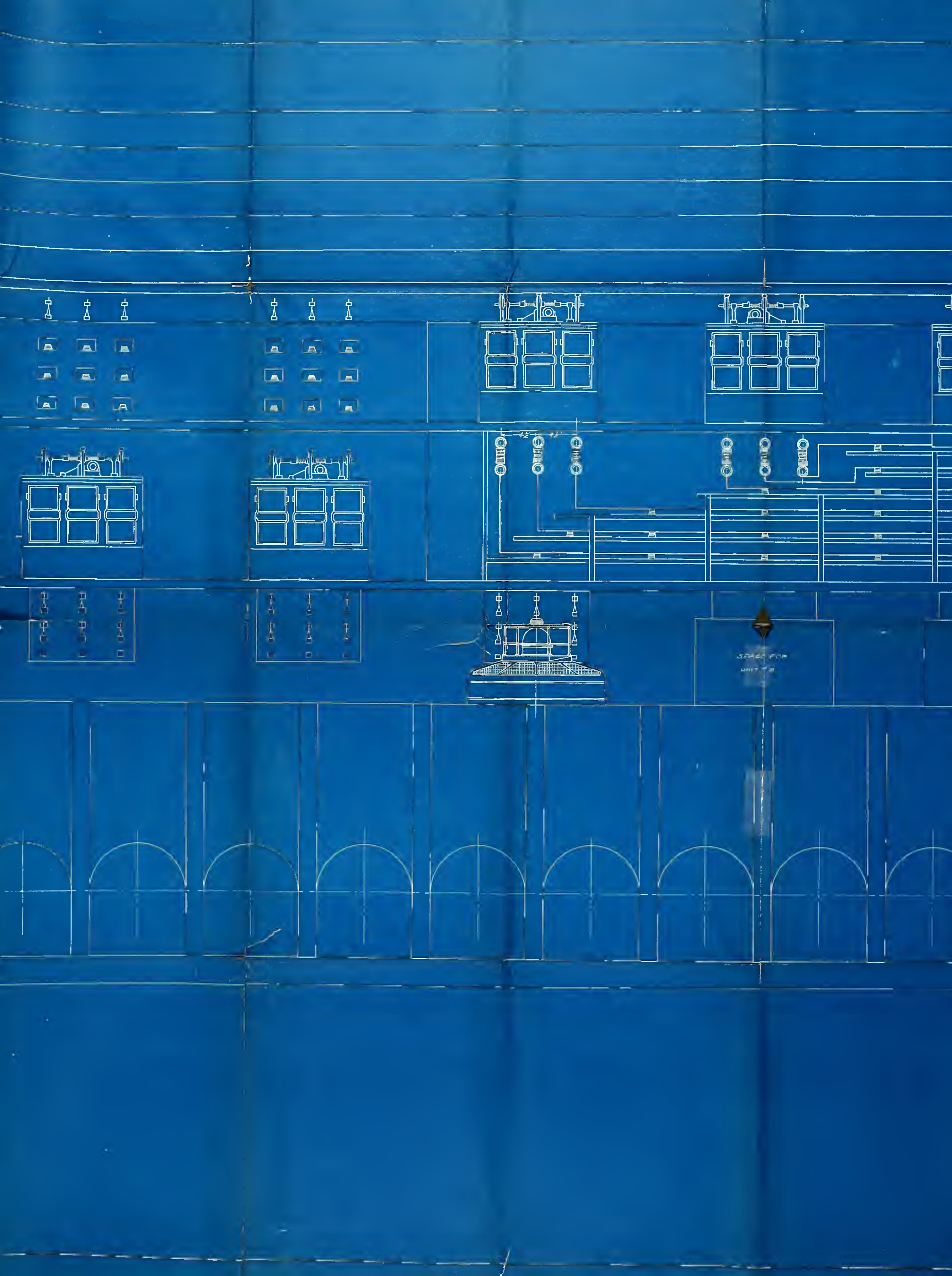
Plan view of Apron showing reinforcing

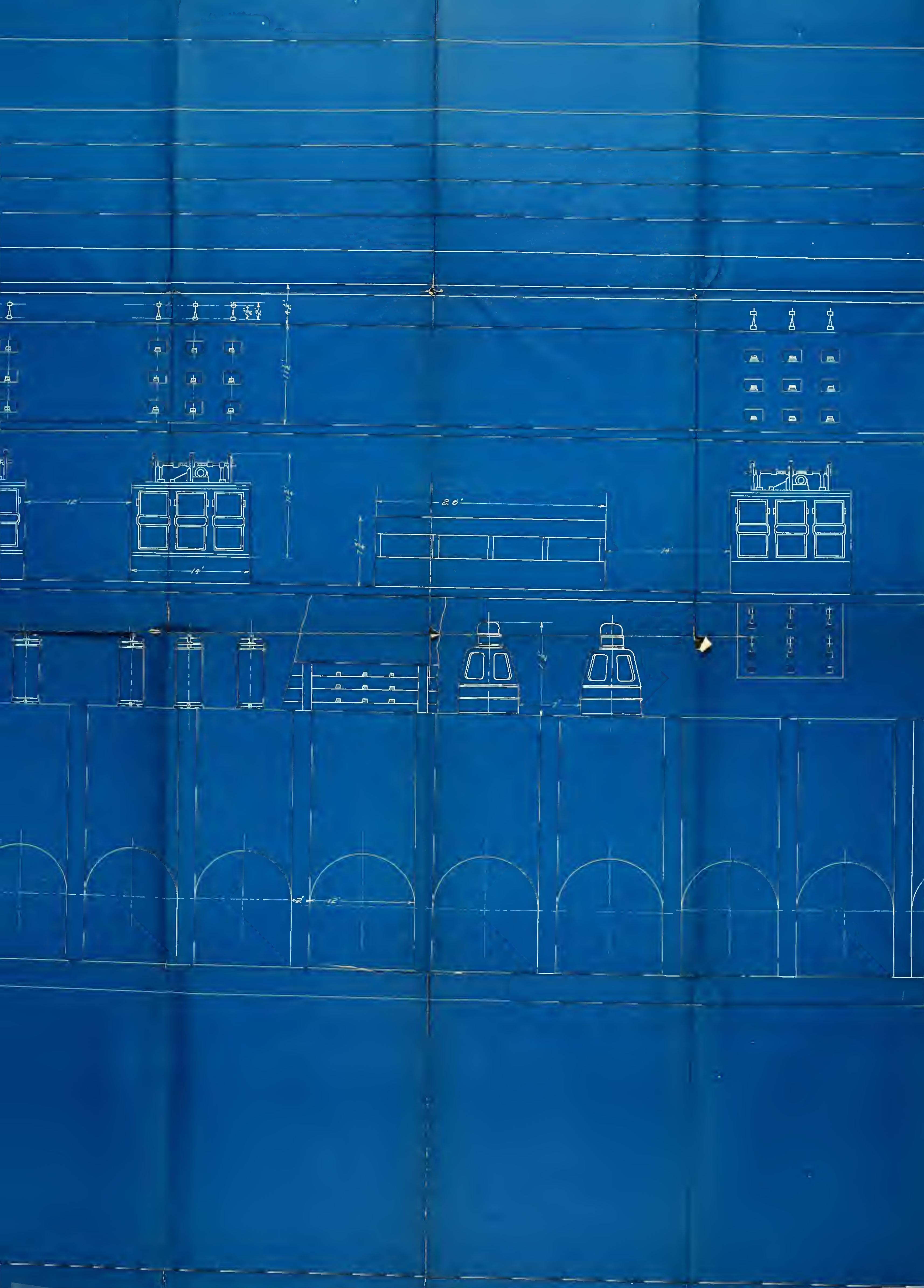


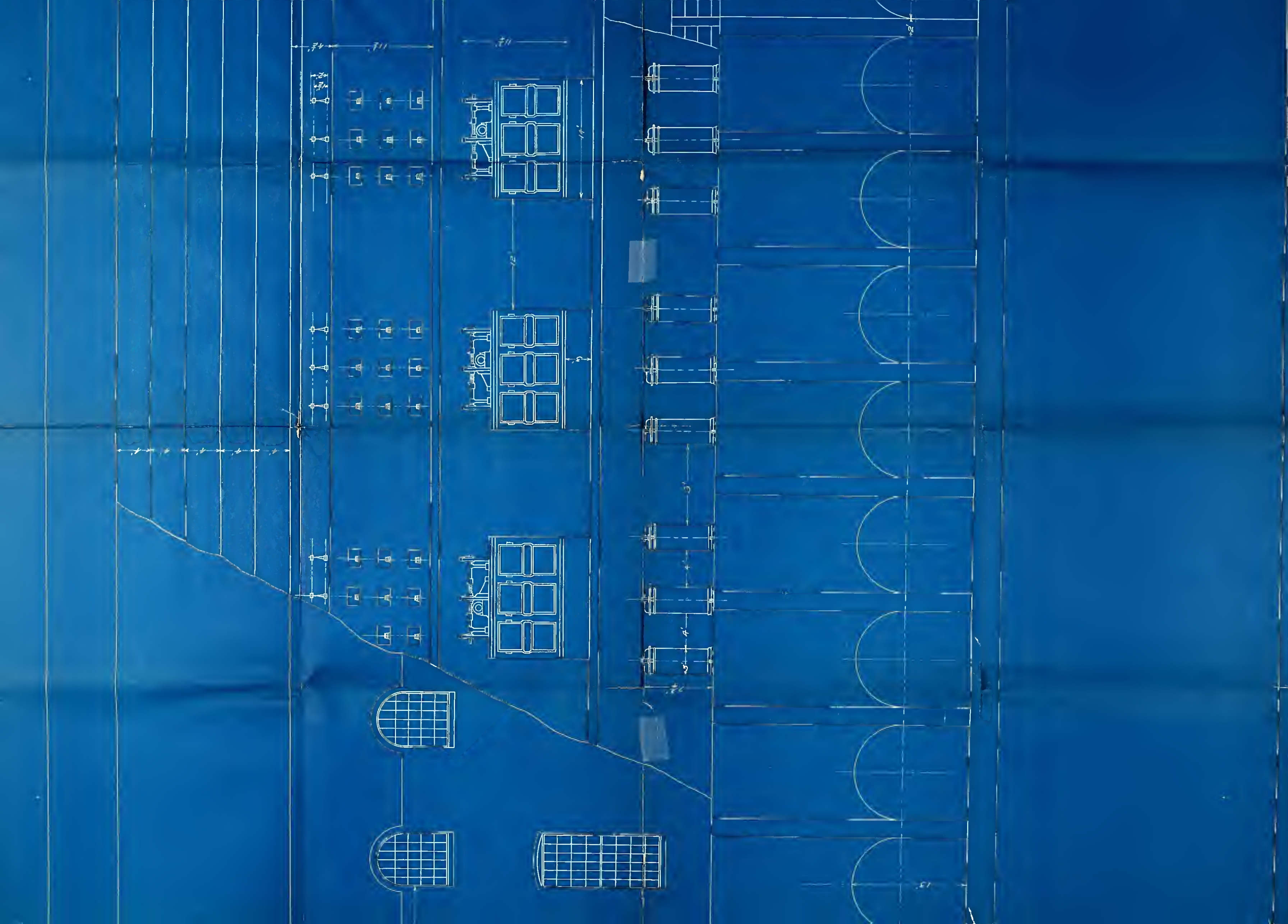
ARMOUR INSTITUTE OF TECHNOLOGY
DESIGN OF SPILLWAY DAM FOR THE PROPOSED
HYDRO-ELECTRIC DEVELOPMENT – THESIS.
MAY 29 1913 SCALE 1" = 2'0"

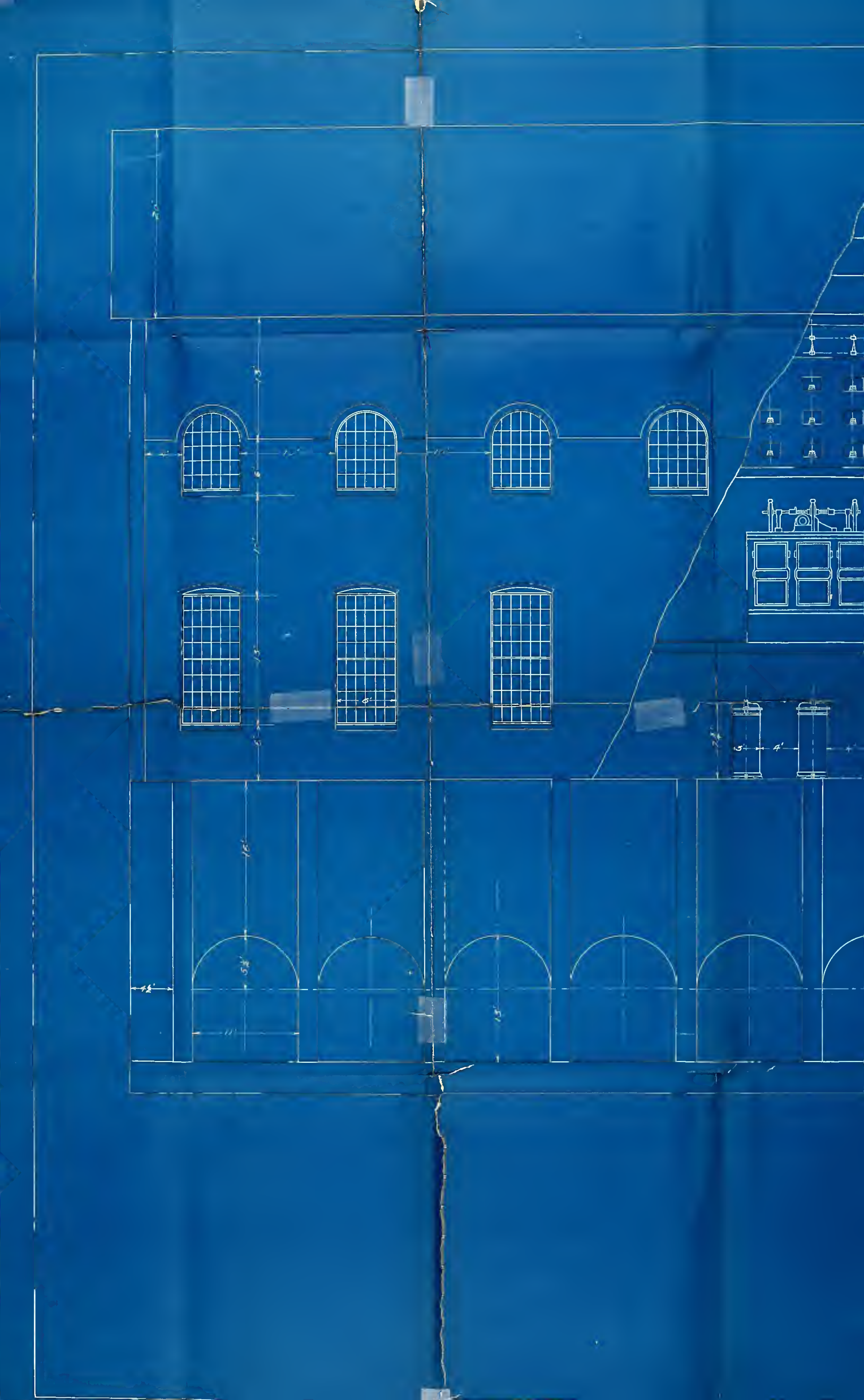


PROPOSED
HYDRO-ELECTRIC DEVELOPMENT
IN THE
DESPLAINS RIVER
ARMOUR INSTITUTE OF TECHNOLOGY
DRAWN BY [illegible] MAY 20 1913.
TRACED BY [illegible] SCALE ¼"=1'-0"
CHECKED BY [illegible] CHICAGO ILL.
LONGITUDINAL ELEVATION.


4½"
4½"
SPARE FOR
UNIT 7


4½'
11½'
7½'





2½'
5½'
4½'